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MAIN STEM RESERVOIR EFFECTS ON WATER QUALITY IN THE CENTRAL MISSOURI RIVER 1952-1957

Joe Kendall Neel, et al

Public Health Service
Kansas City, Missouri

March 1963

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MAIN STEM RESERVOIR EFFECTS ON WATER QUALITY IN THE CENTRAL MISSOURI RIVER

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Main Stem Reservoir Effects On Water Quality in the Central Missouri River 1952 - 1957

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Kansas City, Missouri

March 1963

Frontispiece. Fort Randall Dam and Reservoir. Photo courtesy Missouri River Division, Corps of Engineers.

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SYNOPSIS

This investigation (1952-1957) disclosed water quality changes wrought by early impoundment in main stem reservoirs on the Central Missouri River. These huge impoundments (two have individual capacities that are slightly more than twice the total volume of all reservoirs in the Tennessee River system) markedly altered discharge regimens, reduced turbidity, changed water chemistry, and promoted growth of phytoplankton which also modified water chemistry.

Reservoir storages and capacities allowed almost rigid regulation of discharge beginning in 1955. Impoundments slowed river temperature changes in spring and fall, induced turbidity decreases that carried all the way to the river mouth, promoted photosynthetic precipitation of carbonate that reduced hardness and alkalinity, at times augmented river mineral content by leaching newly inundated soils, often brought about oxygen supersaturation by photosynthesis and air draft to discharge tunnels, reversed the native annual trends in dissolved mineral variation, encouraged development of plankton algae that upon occasion contributed to tastes and odors in water supplies, and allowed development of zooplankters which had notable effects on dissolved nitrogen compounds. Seasonal discharge segments generally maintained their individuality, mixing with water ahead and behind only at their junctions. Turbidity and chemical changes resulted in savings in cost of water treatment where valid comparisons of pre- and post-impoundment practices were possible. In general, water quality changes occasioned by the reservoir system were more frequently beneficial than harmful to water use.

INTRODUCTION

In February, 1952, the stage was nearly set for closure of two large dams (Garrison and Ft. Randall) on the Central Missouri River in North and South Dakota. Several water supplies are taken from this river reach, where water had always been very turbid in open water seasons, and little need existed for taste and odor control at water plants. A plankton reconnaissance made by the Public Health Service in 1950 (1) and a study of the lower Missouri completed in 1945 (2) both demonstrated a very low concentration of taste and odor producing organisms in the main stem and led to the belief that development of such algae had been largely inhibited by high turbidity. State health authorities and waterworks officials expected substantial turbidity reductions in and below the new reservoirs, and feared that resultant algal growths would markedly increase the task of water treatment. This concern led to a recommendation by the Engineering Section, Missouri Basin Health Council, on February 27, that the Public Health Service thoroughly investigate this matter, as the Chief Sanitary Engineers of the ten Basin States were of the opinion that the States individually could not give the problem proper consideration.

The Public Health Service evaluated limnological modifications and developments inherent in the presence and varied operation of these reservoirs, and outlined a program of study that would afford recognition and measurement of reservoir influences upon water quality and their relationships to water treatment. On March 11, 1952, the Public Health Service notified the Division Engineer, Missouri River Division, Corps of Engineers, of the potential

problem, the concern of local and State officials, and action taken in preparing a plan of investigation. On March 27 a detailed list of financial requirements was submitted to the Corps of Engineers. The latter agency was immediately interested in this aspect of its development program, and, on May 17, 1952, agreed to provide major financial support for a study to be initiated and directed by the Missouri Drainage Basin Office, U. S. Public Health Service (since July 1, 1955, Water Supply and Water Pollution Control Activities, Region VI, U. S. Public Health Service).

The investigation began in August, 1952, shortly before closure of Ft. Randall Dam. Its successful prosecution involved the wholehearted cooperation of the Missouri River Division and Omaha and Garrison Districts, Corps of Engineers; State Health Agencies in North Dakota, South Dakota, Nebraska, and Iowa; and local water operators. Original objectives called for: (1) determination of main stem water quality conditions prior to and after significant reservoir impoundment; (2) study of results of clarification upon other naturally turbid streams in the Missouri Basin; and, (3) evaluation of the phytoplankton productive potential of Missouri River water following clarification in large holding basins. The operation plan was soon modified to place emphasis upon main stem reservoir influences; and phases 2 and 3, being unproductive of data with bearing on the central main stem, were dropped in June 1953. Thereafter all attention, except some examination of tributaries, was focused upon the nature, degree, and duration of reservoir influences upon water temperature, turbidity, chemistry, and plankton growth. Ft. Randall Reservoir received full attention for about fifteen months. Garrison (December 1953) and Gavins Point (August 1955)

Reservoirs were incorporated as soon as possible after beginning of impoundment. In its later stages the study covered the river reach from Williston, North Dakota, to Omaha, Nebraska, with sampling from each water supply drawn from the river, and in and below each reservoir.

Cooperative arrangements and contributions of each agency appear in the section describing the investigative program.

Description

The Area

The Missouri River drains the central region of North America, incorporating in its basin about one-sixth of the United States and a small segment of Canada (Figure 1). Its drainage area (529,000 square miles) makes up about one-third of the Mississippi Basin, yet it carries only about 12 per cent of the water delivered by the Mississippi. Paucity of runoff so indicated truly represents the semiarid nature of much of the land.

The basin extends east from the Rocky Mountains in Colorado, Wyoming, and Montana, over the great plains to Iowa and Missouri. Its eastern boundary slants from northwest to southeast in the Dakotas, bringing in the southwest corner of Minnesota, but excluding north and eastern North Dakota and extreme northeastern South Dakota. A relatively narrow neck traverses Iowa and Missouri to the junction with the Mississippi above St. Louis, Missouri.

Most of the basin consists of prairies and plains in Nebraska, South Dakota, North Dakota, Wyoming, and Montana. Mountains occur along the western margin, and badlands (soft materials lying above local base levels) are prominent features ofwestern North and South Dakota and central and northern

FIGURE 1

CENTRAL MISSOURI RIVER
GENERAL REFERENCE MAP

Wyoming. Rich prairie lands occur in southeastern Nebraska, eastern South Dakota, and central North Dakota; and arid or semiarid plains largely occupy the stretch between prairies and mountains. Plains areas contain numerous "breaks" or low hills along river courses, many low buttes, hilly basins, and tablelands. The famous Black Hills interrupt plains continuity in an area extending east and west from the South Dakota-Wyoming border. The Sandhills of northwestern Nebraska also disrupt the plains surface. These low, sandy hills absorb large percentages of the rather limited precipitation, and maintain year round flow in rivers, the Niobrara, Loups, and Elkhorn, leaving their area.

The livelihood of basin residents is largely dependent upon agriculture. Grain and livestock farming utilize most of the land, considerable acreage being devoted to stock raising over a large part of the dry plains area. Sugar beets are grown in widely scattered areas. Agriculture's relations to water resources entail irrigation developments on a number of tributary streams, channel stabilization and flood wall protection on the lower main stem, discharge reduction in a number of sub-basins, etc. Irrigation plays a minor role along the main stem, but some tributaries entering its central region are so utilized.

Basin soils vary from solid rock in several mountainous areas to very deep rich soils in glacial drift prairies and glacial lake beds in the eastern Dakota, southeastern Nebraska regions. Badlands areas are formed of soft clays, shales, and sandstones that easily erode and contribute much silt to local streams that convey it to the Missouri River. The Nebraska Sandhills consist largely of loose dune sand that has been stabilized by

vegetation. Low precipitation has resulted in relatively unwashed soils over a large part of the basin and alkali deposits are common in surface and deeper soils. Soils in the plains sections include the badlands type, sandy areas, clay shale, glacial till, etc. Prairie sections are largely glacial drift or sediment deposited by glacial lakes. Soils of major concern to the central Missouri River region are the badlands type, grassy sandhills, glacial drift and lake prairies, shales, and light clays.

The Weather

As is common for interiors of large land masses, climate over much of the Missouri Basin is semiarid in nature. Precipitation ranges from humid to arid, but both extremes occur in very limited areas. Precipitation decreases from east to west, declining from an annual average of 40-45 inches in Central Missouri, to a yearly range of 10-15 inches along most of the continental divide. Arid conditions (less than 10 inches precipitation per year) are limited to relatively small areas in Montana and Wyoming.

Temperature-wise, most of the basin is a land of extremes, hot to very hot summers alternating with cold to very cold winters. Maximum observed temperatures are above 110°F. in all except high plains and mountainous areas, and minimum observations range from -20° to -60°F. Average annual maximum temperatures are 100°F. or higher over most the area, and mean annual minimums vary from -10° to -40°F. Average July temperature varies from 60° to 80°F., and average January temperatures cover a 5° to 30°F. range. Winter cold in mountains and plains is frequently broken by warm western winds ("Chinooks") that endure from a few to several days, and often melt considerable

ice and snow. Raging blizzards are not uncommon over the prairies and plains, and "ground" blizzards, wind transport of previously deposited snow, frequently interfere with motor travel. Drifts across highways necessitate frequent use of snow plows and convey the erroneous impression of heavy snowfall across the prairie and plains sections, where winter precipitation is actually the minimum for the United States. Weather influences upon discharge and other features of streams are discussed in later sections.

The River

The Missouri is the longest river on the continent, traversing 2,464.4 channel miles from its origin at Three Forks, Montana, to its confluence with the Mississippi north of St. Louis, Missouri. The main stem is formed by the union of three rivers, the Gallatin, Madison, and Jefferson, that start the Missouri upon its way with clear water from the mountains of southwestern Montana and northwestern Wyoming. A pristine clarity is maintained over most of its course in Montana, and the nickname "Big Muddy" is deserved only after degradation by badlands and irrigation drainage begins in eastern Montana. The Yellowstone River is the chief offender in this regard, but much of its silt originates in the Big Horn and Powder River systems. Return of excess irrigation water adds considerable turbidity to the lower Yellowstone. The Little Missouri River brings in silt from the North Dakota badlands; and the Cheyenne, Bad, and White Rivers add contributions from badlands areas in South Dakota. Below this region silt originates in drainage from farm lands, etc. The Platte River, which enters just below the stretch covered by this study, may in season owe much of its discharge to returned irrigation water.

It may be noted (Figure 1) that almost all significant tributaries enter the Central Missouri River from the west. The prairies that constitute most of the adjoining area to the east contain numerous isolated drainage areas that terminate in pothole lakes and other depressions. The James River, which traverses the mid-prairie region for about 750 channel miles, has been dubbed the longest non-navigable river on earth. Below the James, the Missouri receives a number of feeder streams that drain the drift prairies of eastern South Dakota and western Iowa. These streams carry heavy silt loads when in spate. Some have dredged channels.

Terrain in the immediate vicinity of the central river is usually characterized by low hills or "breaks" on one or both sides. In many localities wide bottoms adjoin the river. In the Dakotas, bottoms are frequently wooded and are known as the haunts of deer and beaver. They also serve as winter feeding grounds for livestock. In lower reaches, Iowa and Nebraska, many bottoms are cultivated, and may be with or without the protection of flood walls.

Channel stabilization devices, revetments, wingwalls, riprapping, etc., extend upstream to Sioux City, Iowa. Prior to development of this program, the Missouri was notorious for bank erosion and channel shifting. Bank stabilization and reservoir regulation of discharge in the past few years have practically eliminated the tendency to wander.

Discharge in the main stem has been influenced by one or more large reservoirs since 1938. Normally two high stages occur each year--one in spring originating in snow melt over the plains and prairies, and another caused by mountain snow melt and prairie rains in June. Through water year

1954, discharge averaged 30,800 cfs (22,300,000 acre feet) at Sioux City, Iowa over 19 years of record, and 29,640 cfs (21,460,000 acre feet) at Omaha, Nebraska for 26 years of record. Extremes have ranged from 2,500 to 441,000 cfs at Sioux City, and from 2,200 to 396,000 cfs at Omaha. Minimums at both stations resulted from ice jamming in winter; and both maximums occurred during the April 1952 flood, when heroic measures barely prevented inundation of Omaha, Nebraska.

The stretch Williston, North Dakota, to Omaha, Nebraska, encompasses 1,012.2 river miles, receives a large number of tributaries, and begins only 36.5 river miles below the Missouri's largest tributary, the Yellowstone River. This reach of the main stem courses through plains and prairies. The stream bed is largely composed of sand, and large exposed sand bars are numerous during low water conditions. Shading of water is negligible, although trees usually line the banks. The river received untreated municipal sewage from cities and towns on its banks, and at Sioux City, Iowa, and Omaha, Nebraska, acquired in addition great quantities of organic wastes from packing houses and other industries (7). Average current velocity, considered to be rather high, ranges from approximately 2 to 3.5 feet per second through low and medium stage discharges.

The Developmental Program

Development of water resources in the Missouri Basin has entailed construction of numerous reservoirs by the Corps of Engineers and Bureau of Reclamation. A majority of these impoundments serve multiple purposes, with flood control and power production high on the priority list. The Bureau of

Reclamation reservoirs are located almost exclusively on tributary streams, and most of them afford water for irrigation of farmlands. Corps of Engineer dams have been largely justified by benefits accruing from flood control, and this agency has been responsible for all except one main stem impoundment, and a few reservoirs in the Kansas and Osage River systems. Of greatest consequence to this report are the main stem reservoirs from Ft. Peck to Gavins Point. Some tributary impoundments, such as Boysen Reservoir, which traps about one-third of the sediment load previously discharged by the Big Horn River, have influences extending to the central main stem. In keeping with their irrigation and power utilization, most reservoirs tend to reduce discharge in tributary streams. A number of Federal reservoirs supply water to adjacent municipalities.

The Reservoir System (Main Stem)

Main stem reservoirs occur at intervals from western Montana to the eastern South Dakota-Nebraska boundary. All except the uppermost impoundment (Canyon Ferry) have influenced the central region during the course of this study. Effects of Ft. Peck became localized to the stretch between it and Garrison Reservoir with closure of the latter dam in December 1953. Drawdown of Ft. Peck to aid in filling of Garrison has upon occasion left Ft. Peck with indirect influence upon the river in the Dakotas.

Major features of existing and proposed main stem reservoirs (exclusive of Canyon Ferry) appear in Table 1. Operation of various reservoirs during the course of this investigation is described under discharge in the data presentation section.

Table 1.
Missouri River Main Stem Reservoirs -
Storage Allocations and Hydrographic Features

	Fort Peck	Garrison	Oahe	Big Bend	Ft. Randall	Gavins Point	Totals
Exclusive Flood Control Reserve							
Elevation (1)	2246-2250	1850-1854	1617-1620	1420-1423	1365-1375	1208-1210	
Storage (2)	1,000,000	1,600,000	1,100,000	175,000	900,000	65,000	4,840,000
Annual Flood Control and Multiple-Use Capacity							
Elevation (1)	2234-2246	1837.5-1850	1607.5-1617	0	1350-1365	1204.5-1208	11,800,000
Storage (2)	2,700,000	4,400,000	3,200,000	0	1,400,000	100,000	11,800,000
Carry-Over Multiple-Use Capacity							
Elevation (1)	2160-2234	1775-1837.5	1540-1607.5	1415-1420	1310-1350	1195-1204.5	
Storage (2)	11,200,000	13,600,000	13,800,000	260,000	2,400,000	220,000	41,480,000
Inactive Capacity (3)							
Elevation (1)	2030-2160	1673-1775	1415-1540	1345-1415	1230-1310	1160-1195	
Storage (2)	4,500,000	4,900,000	5,500,000	1,465,000	1,400,000	155,000	17,920,000
Total Capacity (2)	19,400,000	24,500,000	23,600,000	1,900,000	6,100,000	540,000	76,040,000
Average Pool Elevation (1)	2 230	1829	1603	1410	1348	1207	
Depth at Dam (feet)							
Maximum	220	185	205	65	145	50	
Average	200	164	188	65	118	47	
Length (river miles)							
Maximum	190	235	259	75	159	50	
Average	180	218	244	75	128	48	
Shoreline (miles)							
Maximum	1,600	1,600	2,350	120	---	100	
Average				120	550	---	
Area (acres)							
Maximum	245,000	390,000	376,000	19,800	118,400	33,000	
Average	217,000	326,000	311,000	19,800	79,000	30,400	
Closure Date	June 1937	Dec. 1953	Aug. 1958	*	Aug. 1952	Aug. 1955	

(1) Feet above mean sea level
(2) Acre-feet
(3) Minimum power pool
* Not completed
Data supplied by Missouri River Division, Corps of Engineers, U. S. Army

The Investigative Program

Cooperative arrangements established for prosecution of this study are illustrated by the following list of contributions by each agency:

Corps of Engineers, U. S. Army, Missouri River Division, and Omaha and Garrison Districts.

1. Major financial support.
2. Transportation of samples from collectors to laboratories.
3. One year's laboratory chemical analyses.
4. Sample collection at dams, reservoirs, and sediment stations.
5. Reservoir operational data.
6. Drafting and reproduction of figures.
7. Reproduction of annual progress reports.
8. Field chemical analyses at dams and reservoirs.

South Dakota State Department of Health.

1. Total hardness, organic phosphorus, organic nitrogen, and nitrate analyses for stations within that State.
2. Collection of samples at Pierre.

North Dakota State Department of Health.

1. Analyses for total hardness, organic phosphorous, organic nitrogen, and nitrate for stations within that State.
2. Collection of samples at Williston and Bismarck during early phases of the investigation.

Water Departments Collecting Samples.

Williston, North Dakota

Mandan, North Dakota

Water Departments Collecting Samples. (Cont'd)

Chamberlain, South Dakota

Yankton, South Dakota

Water Departments Collecting Samples and Furnishing Analyses.

Bismarck, North Dakota

Omaha, Nebraska

Council Bluffs, Iowa

Water Departments Furnishing Pertinent Information.

St. Joseph, Missouri	Kansas City, Missouri
Atchison, Kansas	Lexington, Missouri
Leavenworth, Kansas	St. Louis, County, Missouri
Kansas City, Kansas	St. Louis, City, Missouri

Assistance with Special Projects.

1. Council Bluffs Water Department filled old settling basins with raw water for testing plankton productive potential of Missouri River water.

2. The Wyoming Department of Public Health collected samples and provided general assistance with work to evaluate influences of Boysen Dam on the Big Horn River.

The Public Health Service furnished over-all supervision and coordination, performed all biological and the majority of field chemical analyses, alerted water operators of impending algal problems, and prepared progress reports and this complete report for the entire investigation.

Sampling and Analyses

The two major objectives--determination of water quality changes at sites of water use, and reservoir phenomena associated with such changes--involved sampling at all water intakes and above, in, and just below each reservoir. Location of water intakes decided their importance in the sampling program. Sites offering greatest opportunity for detection of the nature, degree, duration, etc., of reservoir effects were sampled most intensively. Uncovering detailed reservoir phenomena associated with various modifications of water quality would have required extensive vertical and horizontal sampling programs beyond the personnel resources of this study. Limited vertical sampling associated with routine analyses of inflowing, reservoir surface, and discharged waters was feasible, and permitted considerable correlation of water quality with major reservoir events of annual and cumulative nature.

Routine sampling was instituted at the following locales soon after each of their river areas came under reservoir influences.

1. Council Bluffs, Iowa, Water Intake (1954)
2. Omaha, Nebraska, Water Intake (1952)
3. Yankton, South Dakota, Water Intake (1952)
4. Gavins Point Reservoir (1955)
5. Below Ft. Randall Dam (1952)
6. Ft. Randall Reservoir (1952)
7. Chamberlain, South Dakota, Water Intake (1952) (Listed as Above Ft. Randall Reservoir on tables)
8. Pierre, South Dakota, Bridge (1952)
9. Mobridge, South Dakota, Water Intake (1954)

10. Bismarck, North Dakota, Water Intake (1952)

11. Mandan, North Dakota, Water Intake (1954)

12. Below Garrison Dam (1954)

13. Garrison Reservoir (1954)

14. Newtown, North Dakota, Bridge (1954, discontinued 1955)*

15. Williston, North Dakota, Water Intake (1952, 1955)*

*Listed as above Garrison Reservoir in tables.

Parentheses enclose the year sampling started at each station. The Newtown station, established to analyze water entering Garrison Reservoir, was discontinued when the reservoir reached that point and relocated at Williston. The Williston water intake was utilized during early phases, and then discontinued until it had a close relationship with Garrison Reservoir. Tributary streams were sampled as time permitted, and certain studies were accomplished by boat in and below reservoirs. Nonroutine stations will be mentioned as appropriate data are presented in later sections. Water intakes were above local sewer discharges in all instances.

Analyses were conducted via the cooperative set-up listed above. Type and number performed were not consistent throughout the course of the study, modifications occurring in keeping with river developments, and as the profitless nature of some lines of inquiry was demonstrated.

In 1952 and 1953 phytoplankton samples were collected once each month at Williston, Bismarck, and Pierre, biweekly at Omaha, and weekly at Chamberlain, Ft. Randall Dam, and Yankton, until June, 1953, when they became biweekly. Field chemical analyses (pH, carbonate alkalinity, bicarbonate alkalinity, oxygen, ammonia nitrogen, nitrite nitrogen and phosphate) were made monthly

at all the above stations except Omaha, where they were biweekly. Yankton and Ft. Randall analyses were at biweekly intervals, August - November, 1953. Total alkalinity, total hardness, calcium, magnesium, silica, nitrate, organic nitrogen, total phosphorus, fluoride, sodium, potassium, copper, and zinc were measured through June, 1953, and total hardness, total nitrogen, and total phosphorus were continued through December, 1953.

In 1954 plankton analysis was at weekly intervals at Council Bluffs, Omaha, Yankton, below Ft. Randall Dam, Ft. Randall Reservoir, Chamberlain, Mandan, below Garrison Dam, and Garrison Reservoir. Sampling was monthly or semimonthly at Pierre, Mobridge, and above Garrison Reservoir. Daily turbidity, hardness, and alkalinity records were furnished by water departments at Bismarck, Omaha, and Council Bluffs. Chemical analyses as in effect December, 1953 were at biweekly intervals except above Garrison Reservoir where they were monthly. This plan of operations was continued through June, 1957 with occasional minor changes that will be noted.

ACKNOWLEDGMENTS

The senior author developed over-all and detailed plans for this investigation, directed the activities of all cooperating agencies and personnel, performed a large share of biological and chemical analyses, and prepared this final and three progress reports. H. P. Nicholson supervised field activities and performed field chemical and plankton analyses over the period September, 1954 to June, 1957. The junior author assisted in field operations in 1952 and 1953, and contributed a large number of plankton analyses in 1953 and 1954.

Assistance of many individuals in Federal, State, and local agencies made this study possible and assured its continuance. Space is not available for indicating the part played by each named individual, or for listing every person lending some assistance. Contributions of all are gratefully acknowledged. Key roles were performed by:

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Wendell E. Johnson

R. J. Pafford

Tarmo Waara

George Evans

Edgar R. Wright

South Dakota Department of Health

Charles E. Carl

M. O. Allum

Donald Kalda

O. D. Dunbar

North Dakota Department of Health

Willis Van Heuvelen

R. J. Francis

Council Bluffs, Iowa, Water Department

F. B. Jensen (Deceased)

M. E. Rew

Omaha, Nebraska, Water Department (Metropolitan Utilities District)

F. B. Lasell

Joseph Erdei

Yankton, South Dakota, Water Department

R. N. Whiting

William Wallner

Erwin Hirschman

Chamberlain, South Dakota, Water Department

A. J. Campbell (Deceased)

Forest Seely

Mobridge, South Dakota Water Department

Don Wessel

Emil Pfitzer

Bismarck, North Dakota Water Department

William Yegen

Mandan, North Dakota Water Department

Robert Shaw

Bevan Shaw

Williston, North Dakota Water Department

James Fudge

U. S. Public Health Service

Glen J. Hopkins

Clarence A. Monday, Jr.

<u>U. S. Public Health Service</u> (Cont'd)

Vernon R. Hanson

Francis L. Nelson

PRESENTATION OF DATA

Climatological Conditions

Land areas contributing the major part of runoff to the central Missouri River are contained within the States of Wyoming, Montana, North Dakota, South Dakota, Nebraska, and Iowa (Figure 1). The 1952 Weather Bureau Annual Summaries of climatological data for those states indicate that weather in each was drier and in most warmer than normal. Temperature and precipitation departures from the normal appear in Table 2.

The outstanding climatological event of the year, despite deficient precipitation, was major flooding of the Missouri and most tributaries in March and April. The Weather Bureau attributed flood conditions to rapid thaw of snow and a layer of ice or frozen ground beneath the snow cover. This frozen layer slowed infiltration during a period of rapid thaw in March and allowed most snow runoff to reach the rivers. Flood conditions extended from the Milk River in Montana to the mouth of the Missouri. Several towns were partly or wholly inundated. Flooding of Omaha was barely prevented by last minute elevation of the floodwall.

Precipitation in Montana was only 0.83 inches greater than the driest year on record. The period September 1 - December 31 was the driest in the climatological history of the State of North Dakota. Decreasing amounts of precipitation as the year progressed characterized the weather of a major portion of the area contributing runoff to this river reach.

Table 2.
Temperature and Precipitation Departures from Normal
1952 - 1955

	Iowa		Nebraska		North Dakota		South Dakota		Wyoming		Montana	
	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)
1952												
August	-2.6	1.02	0.4	0.75	0.3	0.24	0.0	-0.08	0.7	0.16	-0.5	-0.13
September	0.5	-3.13	2.6	-1.46	3.6	-0.91	3.7	-1.21	3.8	-0.89	3.2	-0.75
October	-5.0	-2.27	-1.6	-1.33	-0.8	-0.94	-2.0	-1.18	2.7	-1.00	1.1	-0.83
November	1.0	1.01	-2.4	0.31	2.9	-0.14	0.0	0.05	-5.3	-0.35	-2.3	-0.26
December	1.8	0.10	-0.9	0.05	5.3	-0.31	2.6	-0.27	1.7	-0.20	2.1	-0.36
Annual	0.5	-1.57	0.8	-1.92	1.4	-4.87	0.4	-5.16	0.5	-3.19	-0.3	-3.81
1953												
January	2.8	-0.25	7.0	-0.12	7.3	-0.05	6.3	0.06	12.2	0.19	10.1	0.61
February	5.1	0.63	4.5	0.42	8.2	-0.14	4.3	0.62	2.1	0.22	6.8	0.27
March	1.0	1.23	4.9	-0.12	1.5	0.17	2.0	0.15	4.3	-0.52	3.1	-0.22
April	-5.0	0.52	-4.9	0.69	-5.0	1.16	-6.4	1.50	- 4.2	-0.07	- 5.7	0.56
May	-0.4	-1.64	-1.5	-0.88	-2.1	1.80	-2.2	-0.09	- 3.7	-0.19	- 4.4	1.82
June	3.7	0.77	4.7	-0.58	-0.1	1.94	1.9	1.19	2.2	-0.18	- 1.7	0.53
July	-0.3	-0.32	0.7	-0.38	-1.5	-0.96	-1.2	-0.24	2.8	-0.35	- 0.5	-0.68
August	0.6	-1.43	1.2	-0.79	2.6	-0.29	1.1	0.69	1.2	0.23	0.6	-0.09
September	0.4	-3.06	2.2	-1.34	0.5	-0.65	0.7	-1.06	3.2	-0.83	2.1	-0.64
October	5.6	-1.81	4.9	-0.48	7.9	0.06	6.2	-0.39	3.3	-0.64	4.4	-0.27
November	4.0	-0.39	3.1	0.86	8.0	-0.25	5.7	0.05	5.4	-0.09	6.2	-0.26
December	4.1	0.25	2.3	0.31	6.4	0.13	3.3	0.17	1.3	-0.21	5.4	0.09
Annual	1.8	-5.50	2.4	-2.41	2.8	2.92	1.8	2.65	2.5	-2.41	2.2	1.72
1954												
January	-0.7	-0.75	5.0	-0.46	-7.8	0.23	-3.7	-0.36	5.6	-0.10	-6.3	0.69
February	14.4	0.37	15.1	0.03	19.9	-0.24	18.5	-0.02	11.0	-0.31	13.8	0.01
March	-3.3	0.10	-3.0	-0.05	-1.7	0.06	-3.8	0.48	-3.4	0.51	-5.6	0.34
April	3.8	1.80	3.6	-0.76	-2.2	-0.20	0.4	-0.88	2.6	-0.99	-4.1	-0.10
May	-4.8	-0.06	-3.2	-0.16	-3.9	-0.22	-3.0	-0.43	1.3	-0.65	-1.7	-0.73
June	3.3	1.82	2.5	-0.21	-1.7	1.30	-0.9	0.70	0.6	-0.56	-4.0	0.06
July	2.5	-1.82	4.9	-1.82	0.8	-0.55	3.1	-1.04	4.5	-0.28	0.8	-0.46
August	-0.5	3.34	1.1	1.70	-0.6	0.67	0.3	0.09	0.7	-0.23	-1.8	1.29
September	2.0	-1.82	3.7	-0.69	-1.7	1.51	0.1	-0.04	2.7	-0.56	-0.9	0.34
October	-0.8	1.90	-1.2	0.29	0.0	-0.43	-2.1	0.28	-0.1	-0.40	-1.9	-0.18
November	4.1	-1.47	5.8	-0.61	8.3	-0.40	7.4	-0.28	6.4	-0.44	8.3	-0.47
December	3.7	-0.37	4.9	-0.45	9.2	-0.39	4.7	-0.35	1.9	-0.27	4.9	-0.44
Annual	1.97	3.04	3.5	-3.19	1.55	1.34	1.75	-1.94	2.81	-4.28	0.12	0.32
1955												
January	1.3	-0.08	0.4	0.08	4.3	-0.07	3.7	-0.33	0.6	-0.30	1.8	-0.28
February	-1.8	0.21	-4.9	0.19	-3.0	0.05	-3.9	0.33	-3.5	0.14	-3.0	0.22
March	-1.8	-0.72	-1.1	-0.69	-6.1	-0.28	-2.3	-0.75	-5.2	-0.16	-7.6	0.01
April	7.6	0.88	5.7	-1.12	6.8	0.05	6.6	-0.68	-0.5	-0.57	-2.1	0.72
May	3.2	-1.24	4.1	-0.39	3.6	-0.35	5.1	-0.36	1.7	0.01	-2.5	0.97
June	-2.4	-1.47	-3.4	0.42	-1.0	-0.24	-2.3	-0.34	-1.4	0.35	-1.6	-0.74
July	4.9	-0.32	4.6	-1.55	1.8	0.71	3.7	-0.08	1.8	-0.33	-1.6	1.10
August	4.6	-1.97	4.8	-1.43	4.2	-0.38	4.9	-0.24	3.4	0.03	1.9	-0.90
September	2.3	-1.00	2.3	0.62	-0.5	0.08	0.6	0.31	1.0	-0.15	-1.3	-0.62
October	0.9	-0.80	1.7	-1.06	3.3	-0.52	2.4	-0.91	2.6	-0.36	1.9	-0.15
November	-6.4	-1.49	-6.0	-0.49	-12.0	0.27	-9.8	-0.28	-5.7	0.29	-12.3	0.55
December	-4.1	-0.60	-4.4	-0.11	-8.5	-0.13	-8.2	0.34	1.7	0.70	-5.6	0.70
Annual	0.7	-8.61	0.4	-5.53	-0.6	-0.11	0.0	-2.99	-0.2	-0.55	-2.7	1.58

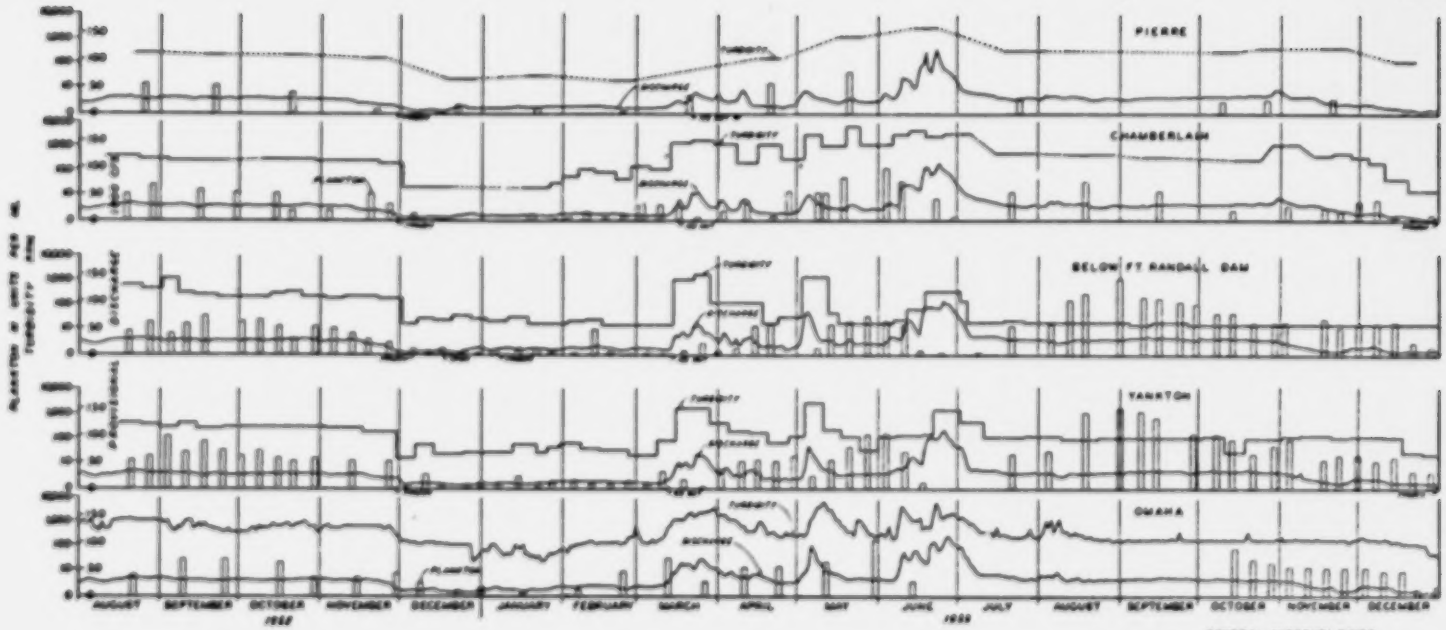
In 1953 (Table 2) all States had temperatures warmer than normal, and Montana and the Dakotas were wetter than usual. Deficient precipitation characterized Wyoming, Nebraska, and Iowa. All months were above normal in temperature except April, May, June, and July in Montana and North Dakota; April, May, and July in Iowa and South Dakota; and April and May in Wyoming and Nebraska. These exceptional months were all colder than normal. June was the wettest month in all States except Wyoming and Montana, where greatest precipitation occurred in May. Precipitation was generally below normal during the last six months of 1953.

Dates of river freeze and breakup for 1952 and 1953 are shown in Figure 2.

The year 1954 was characterized by the warmest February of record in all States except Wyoming, where temperature was also abnormally high. Ice breakup in South Dakota reaches of the Missouri was a month ahead of its usual schedule - beginning at Yankton on February 15 and proceeding to Mobridge by February 25. Certain North Dakota tributaries became ice-free in February but breakup on the main stem there did not occur until April 7. March was colder than normal in the six-state area providing runoff to the Central Missouri and premature thawing conditions were suddenly slowed. Temperature and precipitation departures from normal on a monthly and annual basis appear in Table 2.

Of particular interest to this investigation were heavy local rains in southeastern South Dakota, northeastern Nebraska, and northern Iowa, which elevated river stages and markedly increased turbidity in the reach from Fort Randall to Omaha, Nebraska, at times in May and June. Omaha high stages in June were largely caused by discharges from Iowa tributaries.

FIGURE 8



CENTRAL MISSOURI RIVER
PLANKTON DENSITY, DISCHARGE & TURBIDITY
AUGUST 1952 - DECEMBER 1953

20-A

In 1955, precipitation was below normal in all States except Montana (Table 2). The year was slightly warmer than normal in Iowa and Nebraska, normal in South Dakota, and colder than usual in Wyoming, Montana, and North Dakota. Montana was the coldest and wettest area contributing runoff to the Central Missouri River, and Iowa and Nebraska experienced the warmest, driest weather. Deficient runoff from Iowa was partly responsible for lowered turbidity in the river at Omaha, Nebraska; and lesser amounts of inflow from some lower tributaries were in a measure the cause of more marked reservoir influences.

North Dakota river reaches and Garrison Reservoir were frozen prior to January 1, 1955. The river froze at Pierre and Chamberlain on January 3 and 4, respectively, but ice cover was delayed until January 22 at Yankton. Ft. Randall became completely frozen on January 27. Omaha, Nebraska, never advanced beyond the heavy floating ice stage.

Ice breakup was in early April in North Dakota river reaches, in mid-April on Garrison Reservoir, and from March 12 to April 2 from south to north in South Dakota. In the winter of 1955-56, ice cover extended down to Pierre by November 18. Ft. Randall Reservoir and Yankton, South Dakota, remained unfrozen until December 10.

A new Weather Bureau policy of dividing States into divisions allowed reporting by individual or adjoining drainage areas in 1956 and 1957 (Table 3). In 1956, precipitation was below normal in all areas except the James and Big Sioux Rivers drainage areas in eastern South Dakota. Temperature was lower than usual in all areas but the Yellowstone River drainage and western Iowa. June and December were significantly warmer than usual, and July and August were generally wetter than normal.

Table 3 .
Temperature and Precipitation Departures from Normal, 1956-1957

	Area 1		Area 2		Area 3		Area 4		Area 5		Area 6	
	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)	Temp. °F.	Precip. (in.)
1956												
January	.7	- .20	-2.0	.04	-1.1	- .10	-1.5	- .15	-2.5	.11	-2.1	- .43
February	-3.4	- .16	-2.3	- .34	-2.8	- .28	-4.4	- .17	-6.3	- .29	-2.3	- .63
March	1.2	- .29	1.4	< .01	1.4	- .36	.6	- .95	-4.0	. .10	- .4	-1.34
April	-3.2	- .16	-5.0	-1.07	-6.1	- .51	-6.7	- .62	-6.5	- .78	-3.0	- .99
May	1.5	.08	- .4	.76	.7	- .22	1.1	-1.59	- .2	- .43	2.1	- .89
June	5.8	-1.30	6.3	-1.84	6.8	-1.69	7.1	-1.65	5.7	.08	4.8	-2.03
July	-1.4	- .03	-4.3	1.27	-3.2	1.00	-2.6	- .82	-4.1	.83	-3.2	1.17
August	-2.2	.21	-1.7	.51	-3.0	.72	-2.0	.35	-1.6	1.26	0	.44
September	1.2	- .78	-1.8	- .65	- .5	- .52	< .1	-1.02	-2.8	-1.04	- .9	-1.62
October	1.7	- .51	2.1	- .52	2.8	- .38	4.0	.07	3.6	.19	5.3	- .29
November	- .5	.19	2.2	.31	-1.1	.73	-2.0	.64	.3	.64	- .2	1.51
December	2.9	- .20	3.9	- .04	4.0	- .13	3.5	- .33	4.6	- .26	3.6	- .56
Annual	4.3	-3.15	-1.6	-1.56	-2.1	-1.74	-2.8	-6.24	-13.8	.41	3.7	-5.66
1957												
January	-9.3	- .15	-7.1	- .09	-9.7	- .23	-9.2	- .31	-5.9	- .29	-5.9	- .41
February	2.3	- .05	.6	- .30	2.5	- .28	3.0	- .51	1.6	- .22	4.3	- .79
March	2.9	- .20	3.4	- .50	1.2	- .31	- .4	- .17	1.5	- .50	.9	.22
April	-2.8	.86	-2.3	.36	-4.3	.57	-3.8	.31	-1.2	.48	- .8	- .71
May	1.0	.80	.3	.16	-2.1	2.17	-2.4	2.23	-1.8	1.82	-1.7	.77
June	.1	.62	-1.3	.66	-2.5	.55	-2.6	- .79	-2.2	- .02	-1.9	.94
Semi-Annual Total	-5.8	1.88	-6.4	.29	-14.9	2.47	-15.4	.76	-8.0	1.27	-5.1	.02

Area 1 - Yellowstone River Drainage
Area 2 - Little Missouri, Knife, Heart, Cannonball Rivers Drainage
Area 3 - Grand, Moreau, Cheyenne, Bad, White, Belle Fourche Rivers Drainage
Area 4 - Niobrara and Keyapaha Rivers and Ponca Creek Drainage
Area 5 - James and Big Sioux Rivers Drainage
Area 6 - Western Iowa Drainage

During the first six months of 1957, precipitation was above normal in all areas, and temperatures were slightly lower than usual. Areas with extremes may be noted in the table. Ice breakups in 1956 and 1957 and freeze overs in 1956 were as follows:

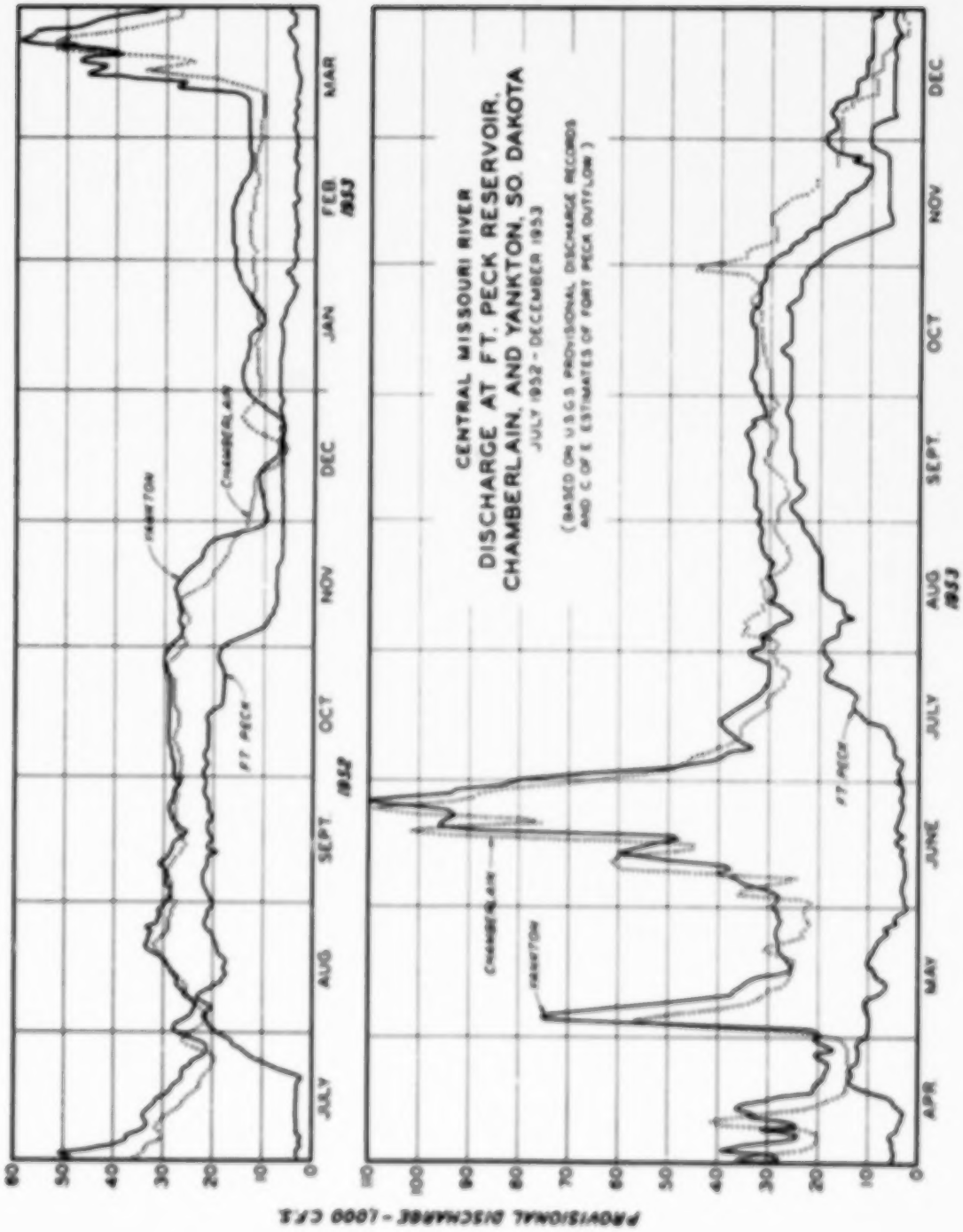
	Breakup		Freeze over
	1956	1957	1956
Williston	April 4	April 6	December 6
Bismarck	April 3	March 21	December 6
Mobridge	March 26	March 20	December 13
Pierre	March 24	March 20	December 8
Sioux City	March 13	March 8	December 10
Omaha	Not frozen	Not frozen	Not frozen

Discharge

It was not possible to relate events completely to the natural pattern of river discharge, since flow regulation by Ft. Peck Reservoir operation was evident at the beginning of this study. Historically, the Missouri River has exhibited two general periods of high stages each year--one occurring in early spring as a result of snow melt over prairie and plains sections, and another in June occasioned by mountain snow melt and general rains in the prairie regions. Minimums occurred in winter. The main commitment for Ft. Peck releases, in addition to power production was maintenance of navigation stages (around 31,000 cfs at Kansas City) over summer and fall following recession of the June rise. Ft. Peck releases compared with discharges at Chamberlain and Yankton, South Dakota, (Figure 3) show how this reservoir influenced discharge patterns prior to significant impoundment in reservoirs within the realm of this study. Time of passage from Ft. Peck to Chamberlain and Yankton was 13 and 15 days, respectively, at discharge levels of 25,000 to 30,000 cfs. Releases ranged from 70 to 90 per cent of discharges at the two river stations.

In 1952 and 1953, Ft. Randall Dam had little effect upon the river regimen, the major portion of flow being passed on through flood control tunnels. Discharge patterns from Pierre to Omaha (Figure 2) show little change above and below Ft. Randall Dam. Following the June rise, volume was maintained by Ft. Peck releases until November of each year. In 1954 entrance of Garrison Reservoir largely ironed out discharge inequalities, and spring and June rises were hardly noticeable in the stretch between Garrison and Ft. Randall (Figure 4). Below Ft. Randall, tributary effects occasioned a distinct although greatly reduced June rise at Yankton and Omaha. In 1955, discharge at all points below Garrison Dam was largely regulated by reservoir releases. Highest discharge occurred above Garrison Reservoir where a maximum of 65,000 cfs was reached, and the lowest mean flow was below Garrison Dam. In terms of annual averages, there was a 1,700 cfs accretion between Garrison and Ft. Randall, and a 3,500 cfs increase between Ft. Randall and Omaha. Garrison Reservoir retained a volume equivalent to a daily input of 4,900 cfs, and Ft. Randall an amount equal to a daily inflow of 600 cfs. Gavins Point closure was effected in August, and it retained 210,200 acre-feet of water by December 31. This quantity, however, accounted for only part of the accretion between Ft. Randall and Yankton and did little to impair the effects of Ft. Randall releases. In 1956, discharges were below 1955 levels down to Ft. Randall Reservoir, below which they were substantially the same. Almost rigid control was exerted by reservoir releases. No station exhibited extremes that did not closely coincide with the level of reservoir output. Discharges over the first 6 months of 1957 also exhibited close reservoir control. Ice jams were responsible for record low winter discharges at Omaha. Monthly and annual averages, and annual maximum and minimum discharges at key localities (Table 4) indicate the progress and degree of reservoir control assumed over the period August 1952 to June 1957,

FIGURE 3


CENTRAL MISSOURI RIVER
DISCHARGE AT FT. PECK RESERVOIR,
CHAMBERLAIN, AND YANKTON, SO. DAKOTA
JULY 1952 - DECEMBER 1953
(BASED ON U.S.G.S. PROVISIONAL DISCHARGE RECORDS AND C OF E ESTIMATES OF FORT PECK OUTFLOW)
YANKTON
CHAMBERLAIN
FT. PECK
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
1952
1953
PROVISIONAL DISCHARGE - 1000 CFS

See the following pages for greater detail.

A

25 D

Table 6.
Average, Maximum, and Minimum Discharge Data
1952 - 1957

Station	Sidney, Montana			Above Garrison Reservoir			Below Garrison Dam			Williston			Mobridge			Pierre			Above Random Sample
	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
1952[1]	4,150	10,100	2,000	18,768	33,000	8,340	22,713	32,300	5,560	22,685	32,600	5,310	22,473	32,300	5,300	22,630	32,300	5,800	22,[illegible]
August	8,152			29,330			28,410			28,360			27,600			27,250			22,[illegible]
September	5,512			23,380			27,810			27,630			27,830			27,060			22,[illegible]
October	6,230			23,530			27,950			28,090			28,630			28,050			22,[illegible]
November	3,881			17,910			18,950			18,960			19,360			20,690			23,[illegible]
December	4,971			11,050			10,330			10,230			9,341			9,013			9,[illegible]
1953	9,514	63,600	3,200	22,670	68,700	8,610	23,270	73,600	6,600	23,500	70,400	3,900	24,580	68,300	3,900	28,510	111,000	3,300	28,[illegible]
January	5,723			11,400			11,130			11,130			11,080			11,060			11,[illegible]
February	5,936			10,430			11,030			11,210			11,340			12,230			13,[illegible]
March	6,025			11,130			12,300			12,890			14,930			20,030			28,[illegible]
April	3,396			16,180			17,340			18,230			19,070			22,010			23,[illegible]
May	9,623			21,130			23,360			23,860			23,050			23,360			32,[illegible]
June	38,660			49,310			51,130			51,880			50,360			64,100			64,[illegible]
July	13,360			27,990			29,190			30,310			30,890			35,060			36,[illegible]
August	6,855			27,130			27,300			27,390			27,660			28,250			29,[illegible]
September	4,081			30,600			30,110			29,340			28,340			28,390			27,[illegible]
October	5,511			33,170			33,530			33,690			33,360			33,130			32,[illegible]
November	4,744			20,090			21,610			22,190			23,230			24,700			23,[illegible]
December	3,584			12,750			9,870			9,640			9,800			9,840			6,[illegible]
1954	9,325	39,800	1,000	22,680	60,000	9,000	21,650	28,700	6,100	21,530	60,000	6,200	21,890	41,200	5,750	22,640	60,800	4,840	21,[illegible]
January	3,177			9,320			9,030			8,690			8,400			8,820			8,[illegible]
February	7,125			14,960			11,240			11,180			10,590			11,180			11,[illegible]
March	5,208			13,730			14,260			14,960			19,460			18,030			19,[illegible]
April	8,083			23,440			22,280			22,450			23,660			23,310			20,[illegible]
May	17,698			32,970			25,230			25,280			25,200			25,590			23,[illegible]
June	20,050			26,970			14,080			14,080			18,630			21,380			23,[illegible]
July	20,260			30,820			32,190			30,890			28,700			28,590			23,[illegible]
August	7,673			36,780			38,930			39,170			39,090			38,160			32,[illegible]
September	5,068			32,130			38,430			38,650			38,870			38,160			38,[illegible]
October	6,015			33,580			37,630			38,360			38,030			32,330			29,[illegible]
November	6,508			18,750			11,090			11,930			12,490			13,880			13,[illegible]
December	5,252			11,150			9,244			7,880			7,374			7,473			6,[illegible]
1955	8,882	38,100	1,500	23,330	69,000	6,400	19,960	47,000	4,700	20,010	46,700	4,100	20,230	47,700	4,990	20,680	48,600	3,490	20,[illegible]
January	3,836			7,029			6,475			6,519			6,519			7,091			5,[illegible]
February	4,618			10,170			7,410			7,148			7,215			7,413			7,[illegible]
March	3,587			13,630			5,330			6,317			7,339			9,312			16,[illegible]
April	12,690			23,360			16,380			13,850			13,260			13,160			12,[illegible]
May	13,900			29,810			30,330			30,210			30,750			27,680			26,[illegible]
June	20,870			41,130			23,250			23,040			24,830			25,360			26,[illegible]
July	14,300			40,690			28,550			28,750			29,710			31,360			29,[illegible]
August	4,743			32,230			25,830			25,360			26,800			26,600			24,[illegible]
September	3,034			29,810			30,630			30,230			30,170			30,860			19,[illegible]
October	5,633			36,910			32,010			32,100			32,280			32,130			31,[illegible]
November	5,039			16,430			16,180			16,760			17,980			19,500			19,[illegible]
December	5,368			12,310			9,944			9,847			8,825			8,855			9,[illegible]
1956	12,230	63,500	3,090	19,530	66,000	8,000	19,040	36,300	6,500	19,180	37,600	6,610	19,860	37,000	6,000	21,190	38,700	6,800	19,[illegible]
January	6,277			13,610			7,853			7,836			8,185			8,838			9,[illegible]
February	5,980			11,970			5,747			5,863			6,179			6,487			6,[illegible]
March	12,730			18,510			9,574			10,120			13,894			17,910			17,[illegible]
April	9,946			17,670			26,960			25,360			27,760			28,520			28,[illegible]
May	28,390			28,110			28,360			28,550			28,820			28,620			29,[illegible]
June	42,760			68,760			32,450			35,110			33,590			33,590			33,[illegible]
July	13,260			25,210			28,830			28,610			30,170			31,630			30,[illegible]
August	6,950			17,430			23,260			23,660			26,150			26,900			28,[illegible]
September	6,242			13,820			20,320			20,230			21,680			21,980			19,[illegible]
October	6,580			12,860			16,150			15,850			15,900			16,050			15,[illegible]
November	8,384			16,590			16,090			16,130			16,980			16,930			15,[illegible]
December	6,325			13,240			11,390			11,510			11,000			10,260			9,[illegible]
1957[2]	10,359	69,000	2,500	26,681	70,000	8,000	16,833	25,200	9,000	15,890	25,900	2,700	17,868	26,000	8,970	16,970	60,400	9,500	19,[illegible]
January	4,297			12,060			11,730			10,900			12,680			10,320			10,[illegible]
February	4,730			12,730			13,960			16,080			14,100			13,210			13,[illegible]
March	8,313			17,960			11,680			12,430			13,690			14,680			16,[illegible]
April	7,348			18,840			17,100			17,100			17,930			18,730			21,[illegible]
May	18,570			35,630			19,090			20,360			20,030			23,350			20,[illegible]
June	36,510			61,720			23,300			23,670			18,800			18,300			21,[illegible]

[1]Pre-reach period
[2]Post-reach period

25 D

B

Table 4.
Average, Maximum, and Minimum Discharge Data
1952 - 1957

Mobridge			Pierre			Above Ft. Randall Reservoir			Below Ft. Randall Dam			Yankton			Omaha		
Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
5,510	22,473	32,300	5,320	22,630	32,300	5,800	22,602	32,100**	6,000*	22,233	31,800**	4,500*	23,537	33,500**	6,500	25,546	34,100**	7,700*
	27,600			27,250			27,040			26,970			28,820			30,660		
	27,830			27,860			27,460			26,920			28,280			30,280		
	28,070			28,050			27,900			27,550			28,780			30,330		
	19,390			20,490			21,250			21,570			23,000			26,700		
	9,541			9,613			9,484			8,277			8,935			9,948		
5,900	24,580	88,300	5,900	26,510	111,000	5,500	28,093	113,500	1,520	26,800	105,000	6,970	29,530	111,000	8,000	33,350	111,000	6,000
	11,080			11,960			11,242			11,550			12,980			13,050		
	11,540			12,250			13,300			13,030			14,970			17,460		
	14,930			20,070			28,400			28,750			33,880			40,890		
	19,070			20,010			23,700			22,290			25,980			33,890		
	25,050			27,960			35,400			32,240			36,970			43,470		
	58,390			66,490			66,300			62,910			65,010			71,450		
	31,820			33,640			36,800			34,350			37,790			43,880		
	27,460			28,750			29,700			27,600			29,420			34,690		
	28,980			28,990			27,500			31,680			33,000			33,910		
	33,360			33,120			32,700			30,720			32,620			32,430		
	23,220			24,700			25,050			14,860			17,720			20,500		
	9,820			9,840			8,560			11,090			13,320			13,950		
6,200	21,890	41,200	5,750	22,440	40,600	4,660	21,192	11,100	4,210	19,990	34,000	7,030	22,160	35,700	9,000	25,960	82,400	5,800
	8,400			8,620			8,540			8,876			10,240			9,123		
	10,990			11,180			11,530			11,460			14,650			16,520		
	18,400			19,070			19,000			17,860			20,730			26,990		
	23,660			23,710			20,600*			23,940			25,530			28,620		
	25,200			25,550			23,500			24,100			26,760			29,860		
	18,430			21,780			23,900			19,280			23,960			42,520		
	28,700			26,590			23,200			29,020			29,650			33,440		
	29,090			39,140			37,500			28,780			30,510			32,310		
	38,870			39,140			36,400			30,160			31,600			32,110		
	30,030			32,370			29,900			26,870			28,880			32,340		
	12,490			13,880			13,100			9,572			11,630			14,510		
	7,574			7,475			6,450			9,268			11,160			12,710		
4,000	20,230	47,700	4,990	20,680	48,600	5,290	20,451	49,000	5,290	21,420	38,700	5,530	22,460	38,000	7,000	23,430	41,900	2,970
	6,519			7,091			5,810			9,346			8,926			9,067		
	7,215			7,413			7,010			9,529			9,196			10,410		
	7,339			9,312			14,900			11,030			15,320			21,470		
	13,200			13,140			12,200			23,960			26,230			29,220		
	38,750			37,460			34,900			29,460			30,920			30,100		
	24,670			25,540			26,700			27,840			29,970			30,290		
	29,710			31,340			29,800			26,950			28,330			31,550		
	24,800			24,600			24,200			33,990			32,070			28,660		
	30,370			30,890			29,570			32,940			34,550			34,400		
	32,280			32,130			31,900			30,260			32,190			32,140		
	17,980			19,520			18,200			11,040			11,840			13,950		
	8,822			8,655			9,100			9,859			9,058			9,047		
4,410	19,860	37,000	4,800	20,590	58,700	4,800	19,971	53,900	5,600	21,830	50,500	4,840	22,840	37,400	7,500	23,620	40,200	4,160
	8,185			8,839			8,400			9,252			8,487			9,219		
	6,079			6,497			6,400			10,230			9,714			9,784		
	13,890			17,950			17,000			16,240			23,810			24,930		
	27,560			28,520			28,000			26,980			28,900			30,250		
	28,620			28,420			28,000			27,730			28,960			30,230		
	33,590			33,900			33,100			33,500			29,770			30,560		
	30,150			31,610			30,500			30,350			30,080			30,830		
	28,150			28,800			28,800			31,920			33,100			33,400		
	20,480			20,960			18,700			33,380			33,940			33,590		
	15,900			16,050			15,500			24,350			25,890			27,930		
	14,380			14,900			15,300			10,310			11,810			13,460		
	11,000			10,240			9,600			8,113			9,197			8,831		
7,780	15,646	26,000	8,970	16,976	61,400	9,500	19,066	67,000	8,300	12,850	38,000	3,460	15,578	33,200	7,500	17,367	50,000	4,520
	10,680			10,320			10,000			8,727			9,222			8,521		
	14,100			13,210			13,500			6,680			8,466			8,981		
	13,690			14,680			16,100			5,902			8,085			10,170		
	17,930			18,730			21,000			14,300			17,740			16,480		
	20,650			25,350			29,200			22,650			26,680			28,020		
	16,800			19,320			24,300			18,480			22,890			31,640		

inclusive.

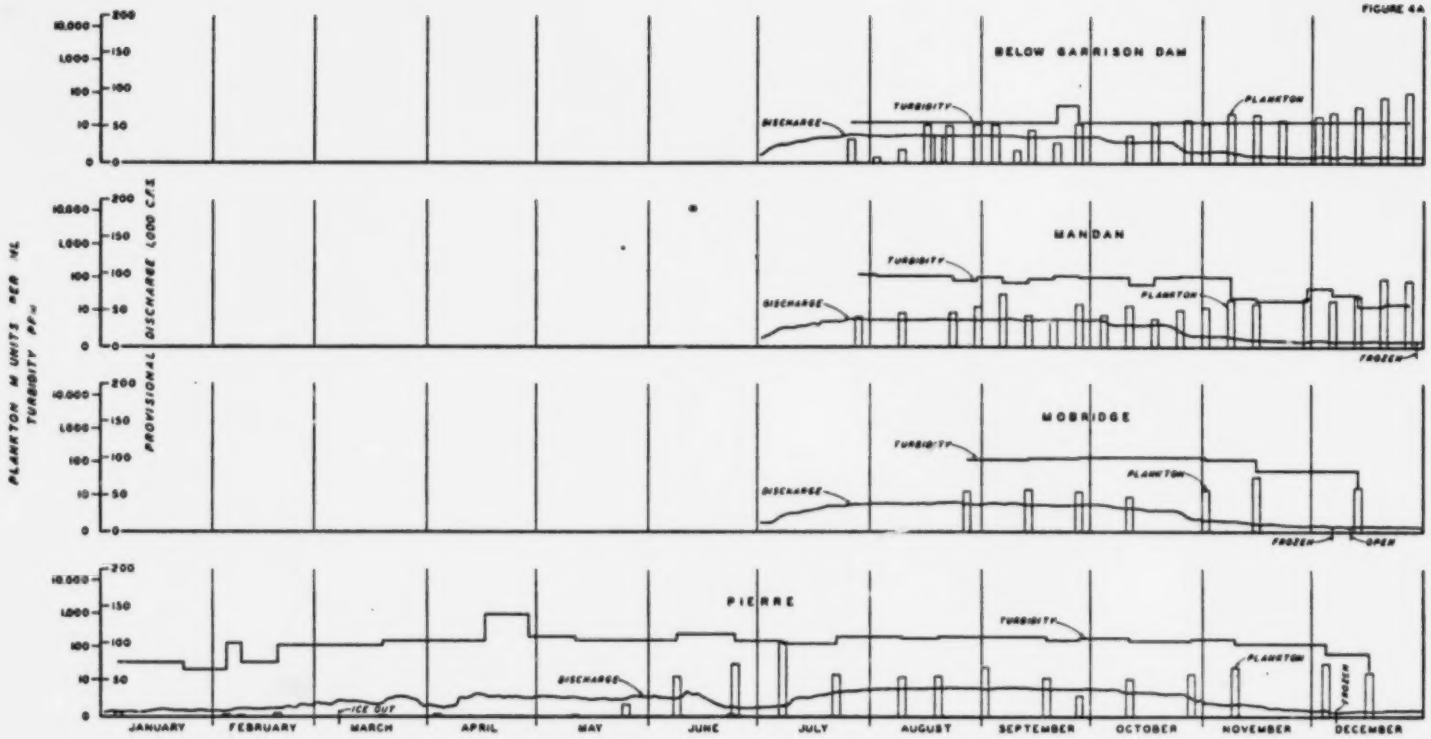
Reservoir Operation

Regulation of Ft. Randall Dam in 1953 resulted in a gradual reservoir build-up, although volume of inflow only slightly exceeded releases, and fell below amounts discharged in September and December (Figure 5). Capacity for significant stream regulation was on hand following recession of the June rise, but impoundment was at the expense of discharges over an extended time, and no marked retention of any seasonal runoff occurred.

In 1954, water level was gradually built up in Ft. Randall Reservoir, reaching 1,343.0 feet above mean sea level on November 30. It lost elevation in December, but finished the year at 1,341.3 feet. Most significant impoundment was during the period August to October, when Garrison releases were increased. Garrison operation provided a continuous water level rise therein from December through April. Volume loss occurred in summer and early fall, but the reservoir began to gain again in October and finished the year at 1,739.6 feet above msl.

Filling Garrison Reservoir was one of the major objectives of 1955 operation. Stepped up releases from Ft. Peck Reservoir assisted in this process from June through October. Garrison discharge was too low to permit Ft. Randall to hold its level, but its losses were not excessive. Ft. Randall releases were drastically cut for a period in August to allow closure of Gavins Point Dam. Water level rose 36.29 feet in Garrison during the year, showing an almost steady climb over the first 8 months but remaining nearly constant thereafter. Pool elevation moved up and down between 1,332 and 1,342.5 feet msl in Ft. Randall

FIGURE 4A



CENTRAL MISSOURI RIVER
PLANKTON DENSITY, DISCHARGE & TURBIDITY
JANUARY - DECEMBER 1954

FIGURE 5

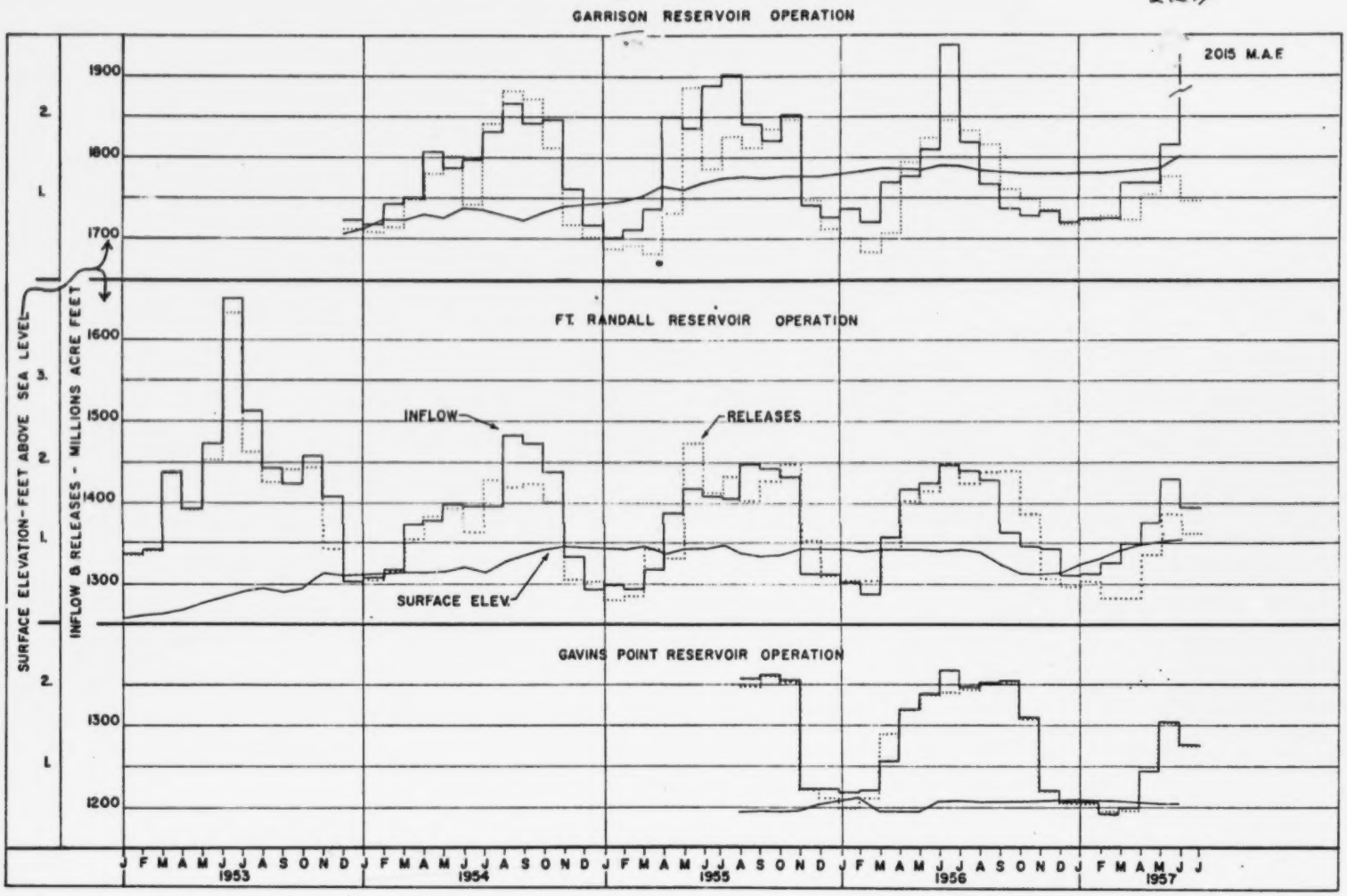
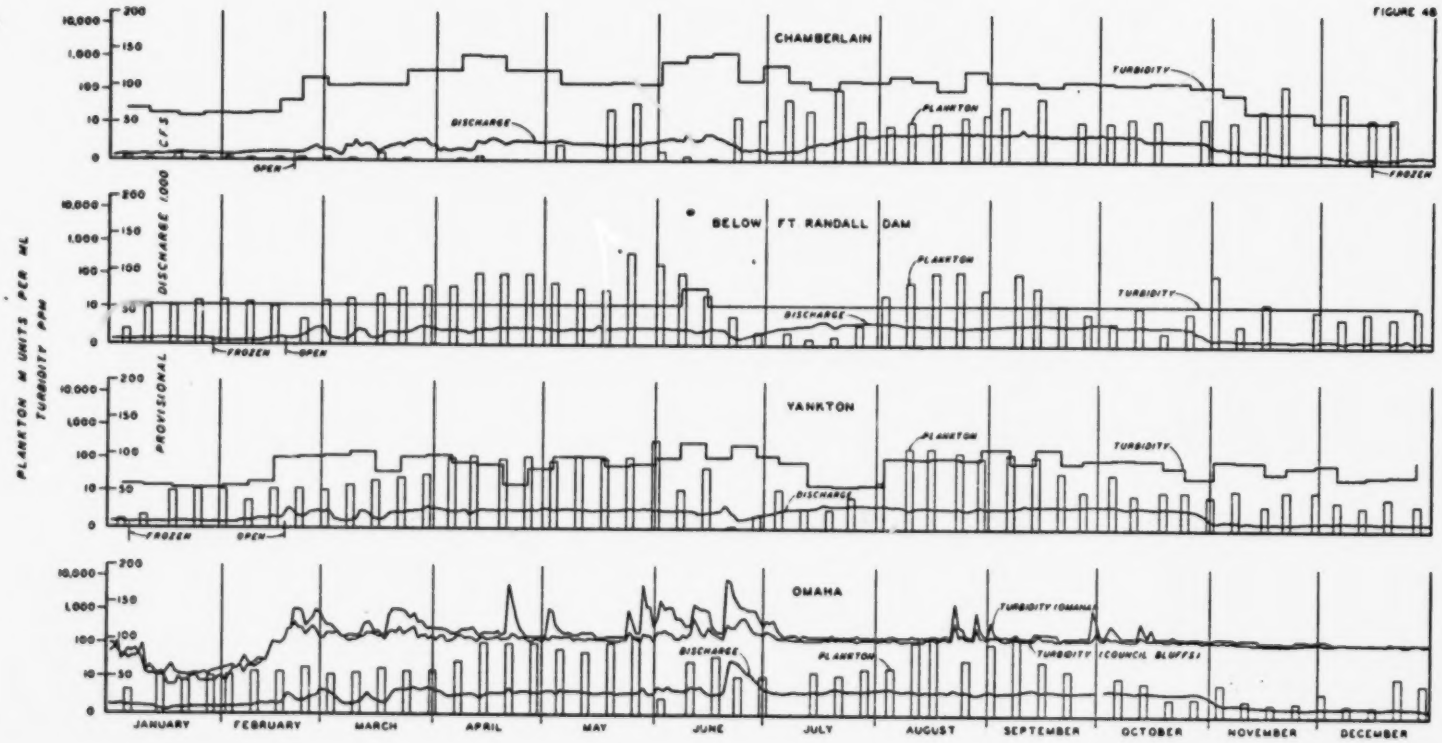

GARRISON RESERVOIR OPERATION
2015 M.A.F.
FT. RANDALL RESERVOIR OPERATION
INFLOW
RELEASES
SURFACE ELEV.
GAVINS POINT RESERVOIR OPERATION
SURFACE ELEVATION-FEET ABOVE SEA LEVEL
INFLOW & RELEASES - MILLIONS ACRE FEET
1900
1800
1700
1600
1500
1400
1300
1300
1200
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J
1953
1954
1955
1956
1957

FIGURE 46



CENTRAL MISSOURI RIVER
PLANKTON DENSITY, DISCHARGE & TURBIDITY
JANUARY - DECEMBER 1954

Reservoir, ending the year 1.2 feet below its January 1 elevation. Gavins Point was largely used as a flow-through reservoir until December.

In 1956, Garrison gained 3.21 feet in depth, rising from 1,776.2 feet January 1 to 1,788.89 feet in July, and then declining to 1,779.41 feet above msl on December 31. From January through June 1957, depth increased 20.59 feet (from 1,779.41 to 1,800.00). Ft. Randall lost 17.9 feet in 1956 (from 1,340.2 to 1,322.3 feet). Its maximum was 1,342 feet on April 15, and its minimum, 1,311.5 on October 23. It gained 32.3 feet during the period January-June, 1957 (from 1,322.5 to 1,354.8). Gavins Point Reservoir showed a net gain of 8.8 feet in 1956, but had a net loss of 2.0 feet over the first 6 months of 1957 (1,206.4 to 1,204.4 feet). Operation during the last 18 months of this study was largely to meet navigation and power commitments, with as much gain in storage as could be accomplished from natural flow. Runoff was deficient in 1956.

Temperature

Water temperature is often indicative of certain reservoir conditions, pollutional and cooling water discharges, etc., and is useful in interpretation of variation in certain chemical and other data. It also, by virtue of its control over decomposition, has indirect effects upon algal growth.

As would be expected, temperature was highest during the mid-summer period and lowest in winter. Minimums ranged from 0 to 3°C., and maximums rose to 28°C. Variation was not unusual when degrees of latitude covered by the spread of sampling stations are considered. Warmest water occurred at Omaha, and there was a general upstream decrease in monthly maximum and average temperatures. Reservoirs generally slowed temperature rise in spring and delayed its

decline in autumn. Their effects in this regard reflected resistance to temperature change inherent in large bodies of water, which in this system of reservoirs is aided by reduced turbidity and restrictions in the relationship of exposed area per volume. Temperature differences between reservoir surfaces and discharged water were never very pronounced and usually did not endure for more than a few weeks at a time. Temperature records were discontinued at all stations upstream from Ft. Randall, except Bismarck, in July, 1956. Return of cooling water to the river above the Mandan intake gave above normal winter temperatures at that location **(refer to Table 5)**

Turbidity

Despite its muddy appearance, the Missouri River did not carry a particularly heavy suspended sediment load in terms of dry weight per volume. Maximum percentages observed during the period 1937-48 (3) were:

Williston, North Dakota	2.19
Bismarck, North Dakota	1.28
Pierre, South Dakota	1.71
Yankton, South Dakota	2.52
Omaha, Nebraska	3.37

The usual load was less than 1 per cent of volume. However, turbidity (suspended sediment interference with light penetration) was very high. This apparently contradictory situation resulted from the widespread occurrence of small, light, flattened clay particles that effectively absorbed light yet contributed aa rather small over-all sediment load.

Prior to significant regulation by any reservoir below Ft. Peck, turbidity relationships were practically identical at all stations. Turbidity was lowest during times of minimum discharge and ice cover, and greatest during high discharges in spring and summer (Figures 3 and 4). Long periods of generally

Table 3.
Average Water Temperatures °C.

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Bismarck	Mobridge	Above Ft. Randall Reservoir	Randall Reservoir	Below Ft. Randall Dam	Reservoir	Yankton	Omaha	Council Bluffs
1952													
August					21		22		29		24	25	
September	19				21		22		25		22	26	
October	12				8		9		11		10	9	
November					8		3		4		5	5	
December	4				0		3		2		2	1	
1953													
January	0				0		3		1		2	1	
February	0				0							1	
March							2		2		2	3	
April					0		12		8		12	9	
May	14				11		17		17		18	19	
June							24		24		23	24	
July					24		28		25		26		
August					23		24		25		24		
September							21		21		22		
October							16		13		13		
November							9		10		9		
December							1		4		5		
1954													
January							2		2		3		
February													
March							3	3	3		4		
April							10	7	7		9		
May							19	13	13		15		
June							20		19		20		
July							27	26	25		25		
August	19	21	21	20			25	25	24		24		
September	14	14	14	15		17	17	23	22		23		
October	13					14	10	14	14		11		
November	5	5	5	5		5	6	11	10		9		
December	0	0	1	3		0	1	4	5		3		
1955													
January		1	1	5	0	1	1	0	0		0	0	1
February	0	0	1	5	0	0	1	2	2		5	0	1
March	1	2	2	3	0	1	1	3	3		2	1	2
April	18	5	5	6	8	13	12	6	6		10	13	12
May	16	10	10	11	13	14	18	12	15		17	19	19
June	18	17	16	16	18	19	22	18	18		21	22	21
July	23	20	18	22	22	25	26	24	22		25	28	27
August	21	21	21	21	23	23	24	25	25		25	26	27
September	15	15	16	15	19	12	13	20	16		19	20	21
October					13		10	16	6		14	16	14
November	2	7	7	4	5	4		6	2		6	4	
December	1	2	2	2	0	1	1	2			5	1	
1956													
January		2	3	4	0	1	1	2	2		6	1	1
February		1	1	2	0	2	1	2	3		2	1	1
March		4	4	3	0	2	4	4	4		3	1	2
April	6	5	4	12	6	5	6	6	6		6	8	8
May	17	8	8	14	10	11	16	16	15	14	13	15	15
June	20	16	15	18	17	19	23	23	21	22	24	24	24
July	23			21	20	22	24	26	26	26	26	26	25
August					21	22	25	26	26	27	26	26	25
September					17	16	18	21	21	21	21	20	19
October					14	12	14	16	16	19	16	16	15
November					8	4	6	11	11		7	6	6
December					1	2	5	4	4		3	1	1
1957													
January							2	1	1		2	1	
February							3	4	4		3	1	
March							3	5	5		4	2	
April							9	9	7		10	11	
May							15	14	13		15	16	
June							21	20	17		21	23	

uniform discharge, roughly July to November, were characterized by rather uniform turbidity near the middle ranges. Turbidity was consistently greatest at Omaha.

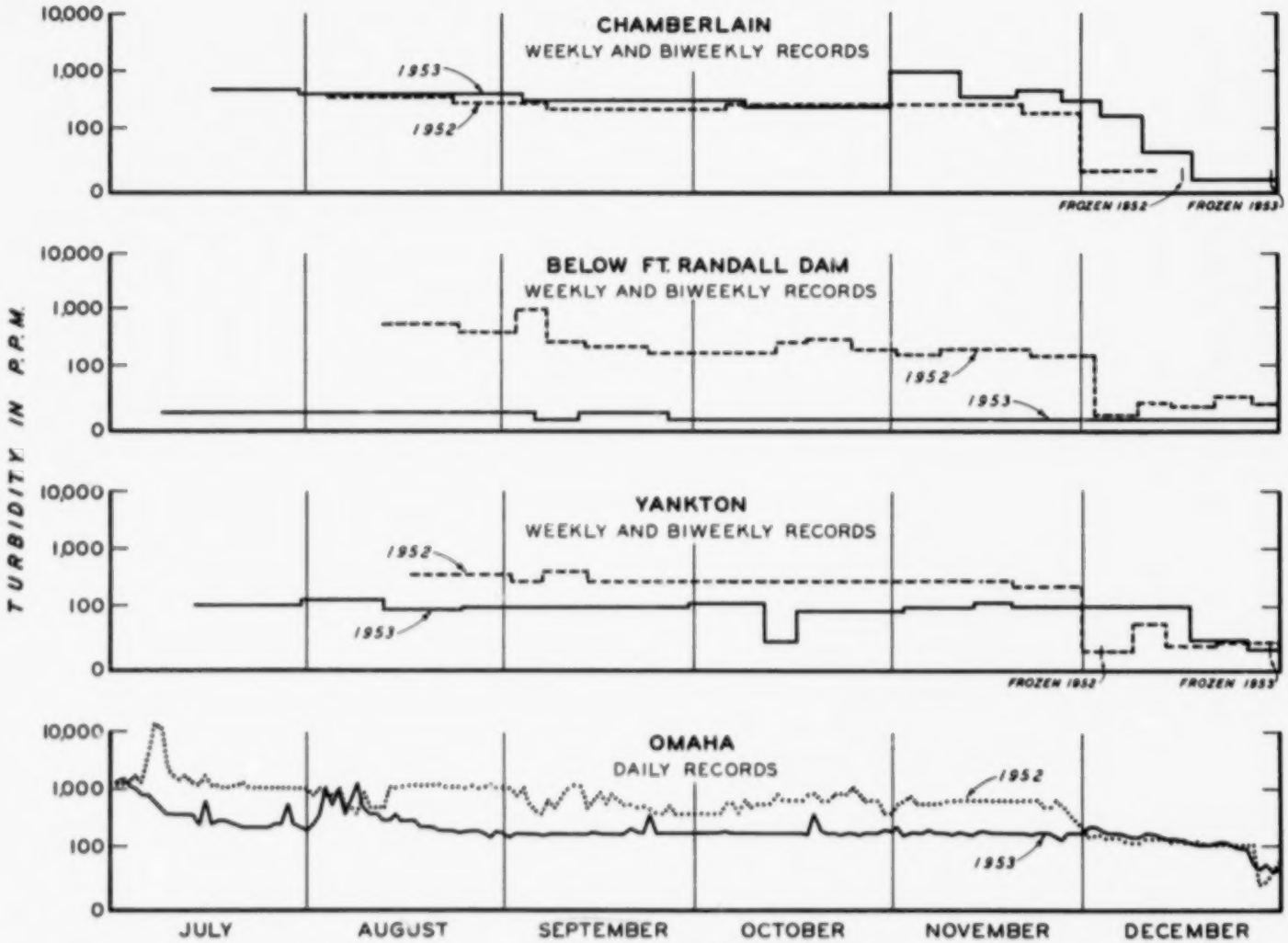
Associations of turbidity extremes with ice cover and high discharges suggest that surface runoff, which is practically nonexistent when the river is frozen and is largely responsible for high stages in spring and summer, brought the major share of suspended matter to the river. Bank erosion along the main stem and major tributaries, an action most common during high stages and negligible under ice cover, apparently had some part in turbidity contributions. Bed scour appeared to be unimportant, as bottom sediment particles have little clay and offer but slight barriers to light penetration when temporarily brought into suspension.

Table 6.
Average Annual Turbidities
ppm

	1953	1954	1955	1956	1957 (½)
Above Garrison			633	386	811
Below Garrison		<35	< 35	<35	<35
Bismarck	957	89	77	65	35*
Mobridge			152	90	57
Pierre	1,046	260	299	350	791
Above Ft. Randall	1,782	390	431	478	214
Below Ft. Randall	166	<35	< 35	<35	<35
Yankton	419	124	93	<35	<35
Omaha	827	545	338	299	351
Council Bluffs			225	181	393

*Mandan

Reservoir effects upon turbidity were striking, as may be noted by annual average turbidities at selected stations (Table 6). Ft. Randall effects during



CENTRAL MISSOURI RIVER
TURBIDITY COMPARISONS
JULY - DECEMBER, 1952 AND 1953

FIGURE 6

the last six months of its first year of impoundment are graphically represented in Figure 6. Reductions at Yankton and Omaha were also evident in 1953 (Figure 6). Bismarck, Pierre, and Chamberlain showed a considerable decrease following Garrison impoundment in 1954, and Yankton and Omaha benefited further from Gavins Point closure in 1955. Increases at Pierre and Chamberlain in 1955, 1956, and 1957 resulted from construction activities at Oahe Dam Site. Turbidity at Yankton was affected by earth moving at Gavins Point in 1953 and 1954.

Reservoirs also promoted greater uniformity in turbidity, and in most cases substantially reduced annual maximums. Uniformity was most marked immediately below reservoirs, but range of variation was considerably narrowed at all stations. Progressive downstream increases were the rule below each reservoir when earthwork activities at dams were not involved.

Fluctuation in reservoir level markedly influenced turbidity at Chamberlain in 1955. For a while that year this station was situated in the headwaters of Ft. Randall Reservoir, and silt was precipated on the bottom. When the reservoir fell below this elevation, accumulated silt beds were stirred up by currents.

Downstream extent of turbidity reduction by this reservoir system is shown in Table 7, which was developed from water plant records covering a number of years. Sharp reductions following dam closures leave little doubt that turbidity was affected all the way down to the Mississippi River. Another feature shown by this table (also by Table 6, for Omaha and Council Bluffs) is marked variation between nearby points. Differences between St. Louis City and St. Louis County, whose intakes are located 0.6 miles apart on the same bank, were more marked in the post- than in the pre-impoundment period. Intake

Table 7.
Average Annual Turbidities ppm, Water Plant Records

River Miles	470.5	434.5	408.8	385.0	382.0	226.8	196.7	36.6	36.0
	ST. JOSEPH MISSOURI	ATCHISON KANSAS	LEAVENWORTH KANSAS	KANSAS CITY KANSAS	KANSAS CITY MISSOURI	GLASGOW MISSOURI	BOONVILLE MISSOURI	ST. LOUIS CITY	ST. LOUIS COUNTY
1918				2,329					
19				1,820					
1920				2,549	2,500				
21				1,817	2,000				
22				2,477	2,600				
23				3,264	3,800				
24				2,208	3,100				
25				2,162	2,500				
26				2,203	2,600				
27				3,251	3,100				
28				2,881	2,600				
29				2,246	2,000				
1930				2,040	2,200			1,881	
31				1,812	1,900			1,578	
32				3,162	2,400			2,637	
33				2,857	2,000			1,920	1,900
34				1,648	1,700			1,300	1,300
35				2,308	2,200			1,400	1,400
36				1,454	1,800			1,600	1,500
37				2,692	2,700			2,000	2,300
38				2,304	2,300			1,800	2,000
39				1,933	1,700			1,600	1,800
1940	3,300		2,810	2,110	2,400			1,900	1,900
41	4,800	1,500	3,196	2,899	2,700			2,100	2,300
42	3,700	2,200	3,237	2,192	2,200		6,300	1,610	1,700
43	2,600	1,200	2,161	1,668			1,800	1,250	1,300
44	3,100	1,500	2,380	2,052			1,900	1,800	1,900
45	3,100	2,000	1,073	2,085	2,300		1,800	2,100	1,500
46	2,800	2,500	1,048	2,330	2,500		2,200	2,000	2,200
47	2,900	3,000	1,793	1,450	1,700		1,100	1,278	1,100
48	1,700	900	1,994	1,849	2,200		1,600	1,600	1,700
49	1,600	1,000	1,551	1,450	1,800		1,500	1,300	1,500
1950	2,375	2,000	1,861	1,870	2,200		1,800	1,760	1,700
51	2,539	1,500	2,060	1,890	1,200		1,300	1,400	1,400
52	1,970	2,000	1,400	1,308	1,600		1,200	1,100	1,100
53	998	1,500	775	803	850	891	800	760	800
54	1,064	1,200	770	810	900	928	1,000	890	800
55	714	350	534	570	480	668	1,000	606	600*
56	525			470	490		500	475	450
57	785			800	890		794	646	650

*January through November only.

locations are believed responsible for differences between Omaha and Council Bluffs. The Omaha intake is thrust against the main path of flow, whereas the one at Council Bluffs draws from slower, alongshore currents.

Suspended Sediment

Reservoir reductions of suspended sediment load are clearly demonstrated in Table 8. Ft. Randall effects were significant beginning in 1953 and Garrison influences were first evident in 1954. As with turbidity, reductions in suspended sediment carried to the mouth of the river.

Hydrogen Ion Concentration*

In the Missouri River, and in most natural waters of fair mineral content, hydrogen ion concentration (pH level) is normally determined by relative amounts of carbon dioxide, bicarbonate, and carbonate. In general practice, pH values above 8.0 are assumed to denote the presence of carbonate; a level of 8.0 indicates bicarbonate alone; and values below 8.0 show the occurrence of free carbon dioxide. Carbon dioxide, usually produced by decomposition and respiration, will react with any carbonate present to form bicarbonate and water. Photosynthesis by aquatic plants utilizes carbon dioxide, removing it from bicarbonate and producing carbonate when no free CO_2 exists. Carbonates of calcium and magnesium are but weakly soluble and quantities of them leave solution. Decomposition and/or respiration thus tends to reduce pH and increase bicarbonate, whereas the tendency of photosynthesis is to raise pH and reduce bicarbonate. Extent and rate of decomposition are largely determined by quantities of organic matter and temperature. Photosynthesis per se is mainly dependent upon availability of plant nutrients and light. Some nutrient elements originate in decomposition

*Methods used for pH and other chemical measurements were according to "Standard Methods," 9th ed., 1946.

Table 8.
Annual Suspended Sediment Loads
Tons per cfs

	Williston	Bismarck	Pierre	Yankton	Omaha	St. Joseph	Kansas City Missouri	Hermann
1949	3.704	4.901	7.911	8.779	9.054	14.312	12.192	9.701
1950	4.669	6.009	10.624	11.692	11.555	14.431	13.652	8.832
1951	3.816	4.647	6.603	8.946	13.967	15.055	14.905	8.319
1952	4.575	6.067	8.745	11.186	8.880	9.497	9.172	6.780
1953	3.984	4.777	8.147	5.460	6.660	6.966	6.525	4.687
1954	3.172	2.009	3.571	3.308	3.846	6.335	5 506	4.621
1955						4.256	4.069	3.884

and in many instances decreased rate of decomposition is accompanied by a slow-down in photosynthesis.

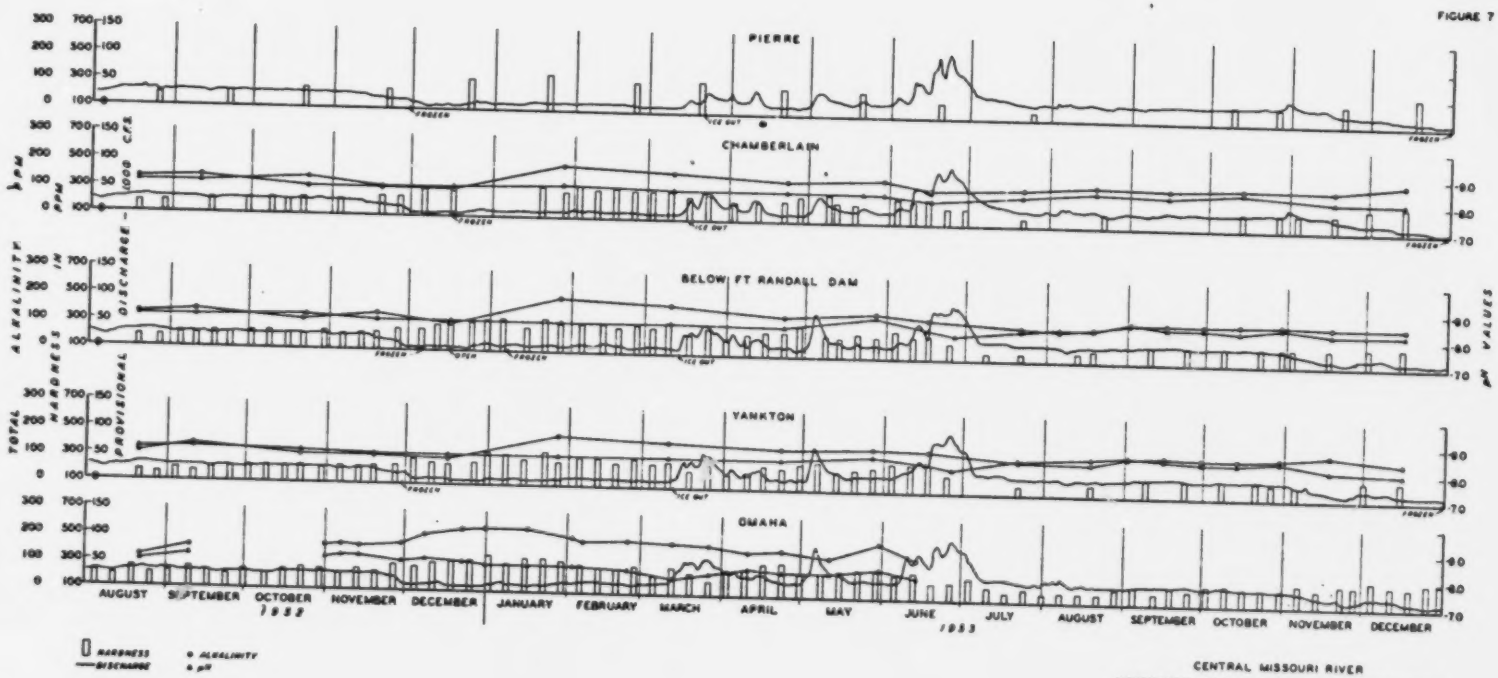
In the Missouri River the usual pH range at middle and low discharges, and when decomposition and photosynthetic influences were largely inoperative, appeared to be 8.1 - 8.3 (Figures 6 (1953), 8 (1954). In view of other chemical features, this pH level demonstrated the normal presence of a readily soluble form of carbonate (Na_2CO_3 or K_2CO_3). Maintenance of this value over long periods of time in the unregulated river indicated a general low level of organic decomposition.

Over the period of study, pH variation was induced by changes in discharge, photosynthesis, brief periods of reservoir stratification accompanied by increased decomposition in deeper waters, and entrance of municipal pollution. More details on pH appear in the alkalinity sections.

Alkalinity

Alkalinity of natural waters is usually referable to quantities of carbonate and bicarbonate in solution. Salts of other weak acids, e.g., phosphates, are very infrequently present in sufficient concentration to have noticeable influence. Carbonate (CO_3) and bicarbonate (HCO_3) ions most frequently occur combined with calcium, magnesium, sodium, and potassium. Calcium and magnesium carbonate are but weakly soluble and tend to precipitate when formed by photosynthetic breakdown of bicarbonate. Sodium and potassium carbonate are readily soluble, but are much rarer in natural waters than the calcium and magnesium forms. All four forms of bicarbonate freely dissolve in water.

FIGURE 7



CENTRAL MISSOURI RIVER
HARDNESS, ALKALINITY, pH AND DISCHARGE
AUGUST 1952 - DECEMBER 1953

36-A

XXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXX

Carbonate Alkalinity

The Missouri River receives soluble carbonates in small quantities from numerous alkali deposits in arid and semiarid portions of its drainage basin. Alkalinity apparently caused by these substances varied from about 0.1 to 6.0 ppm during the early part of this investigation, and its presence resulted in rather uniform pH values in the range 8.1 - 8.3 when influences of photosynthesis, decomposition, dilution by surface runoff, etc., were not significant. In areas of greater rainfall, e.g., the Ohio Basin, the occurrence of carbonate in streams is practically always indicative of photosynthesis, since only calcium and magnesium carbonate remain in those well-washed soils, and their solubility depends upon transformation into the bicarbonate state by dissolved carbon dioxide (carbonic acid).

In the early phases of this study carbonate variation was induced by high discharges that diluted it beyond measurement, increased CO_2 production that converted it to bicarbonate, and photosynthesis, which produced it from bicarbonate. Its relationship to high discharge may be noted by reference to Table 9 and Figure 7 for Omaha and Chamberlain (1953). Increased CO_2 production apparently resulted from pollutional discharges that affected the river at Williston, Bismarck, and Omaha in 1952 - 1953. At Bismarck and Williston, CO_2 production apparently was depressed in winter and pH rose to a level indicating occurrence of carbonate. Omaha is situated below the entrance of considerable amounts of raw organic wastes from municipalities and packing houses (Sioux City, Iowa; Blair, Nebraska), and carbonate disappeared there after the onset of cold weather. Influences of organic wastes have been noted to extend farther down streams when low temperature slows bacterial action, and this phenomenon at Omaha was not unusual.

Table 9.
Summary of Individual Temperature, pH, and Alkalinity Measurements
1952 - 1953

Station	Date	Temp. °C.	pH	CO_3 Alk. ppm	HCO_3 Alk. ppm	Total Alk. ppm
Williston, N.D.	9-10-52	19	7.2	0.0	152	152
	10- 9-52	12	7.2	0.0	95	95
	12- 1-52	4	7.4	0.0	198	198
	1- 7-53	0	8.1	-	200	200
	2- 2-53	0	8.1	-	185	185
	5- 5-53	14	7.2	0.0	165	165
	7- 2-53	-	7.2	0.0	98	98
Bismarck, N.D.	8-16-52	21	8.2	6.0	109	115
	9-10-52	21	7.5	0.0	160	160
	10-17-52	8	7.65	0.0	162	162
	11-14-52	8	7.2	0.0	172	172
	12-19-52	0	8.2	-	208	208
	1- 9-53	0	8.2	-	190	190
	2-19-53	0	8.15	-	176	176
	4- 8-53	0	8.0	0.0	140	140
	5-12-53	11	7.8	0.0	164	164
	7-20-53	24	7.6	0.0	120	120
	8-26-53	23	7.6	0.0	150	150
Above Ft. Randall Reservoir	8-18-52	22	8.2	6.0	124	130
	9-11-52	22	8.2	4.0	134	138
	10-22-52	9	8.4	4.3	102	106
	11-19-52	3	8.1	1.3	103	104
	12-16-52	3	8.1	2.0	99	101
	1-27-53	3	8.2	4.0	188	192
	3-10-53	2	8.1	2.3	171	173
	4-22-53	12	8.1	2.0	148	150
	5-27-53	17	8.2	4.0	156	160
	6-16-53	24	7.9	0.0	130	130
	7-21-53	28	8.1	4.0	133	137
	8-18-53	24	8.3	7.0	145	152
	9-15-53	21	8.2	5.0	142	147
	10-13-53	16	8.4	8.0	146	154
	11-17-53	9	8.1	2.0	149	151
	12-15-53	1	8.1	4.0	176	180
Below Ft. Randall Dam	8-19-52	29	8.2	6.0	118	124
	9-10-52	25	8.2	6.0	132	138
	10-21-52	11	8.3	5.0	102	107
	11-18-52	4	8.1	2.6	133	136
	12-16-52	2	8.1	2.4	97	99
	1-27-53	1	8.05	0.1	198	198
	3-10-53	2	8.1	2.0	179	181
	4-22-53	8	8.1	4.0	143	147
	5-27-53	17	8.3	10.0	153	163
	6-16-53	24	8.1	4.0	141	145
	7-21-53	25	8.1	4.0	118	122
	8- 5-53	26	8.2	7.0	111	118
Below Ft. Randall Dam (cont'd)	8-18-53	24	8.2	4.0	119	123
	9- 1-53	26	8.5	10.0	136	146
	9-15-53	21	8.5	10.0	134	144
	9-29-53	17	8.3	7.0	136	143
	10-13-53	16	8.2	4.0	144	148
	10-29-53	14	8.3	8.0	142	150
	11-17-53	9.5	8.1	2.0	145	147
	12-15-53	4	8.1	0.1	143	143
Yankton, S.D.	8-20-52	24	8.2	6.0	98	104
	9-10-52	21.5	8.3	4.0	131	135
	10-21-52	10	8.2	6.0	99	105
	11-18-52	5	8.1	2.6	101	104
	12-16-52	2	8.1	3.0	93	96
	1-27-53	2	8.1	2.0	181	183
	3-10-53	2	8.1	4.0	162	166
	4-22-53	12	8.1	4.0	146	150
	5-27-53	18	8.3	8.0	149	157
	6-17-53	23	8.1	6.0	146	152
	7-21-53	26	8.3	8.0	118	126
	8-18-53	24	8.4	8.0	111	119
	9- 1-53	27	8.5	10.0	137	147
	9-15-53	20	8.4	10.0	139	149
	9-29-53	18	8.3	7.0	139	146
	10-13-53	14	8.3	4.0	140	144
	10-29-53	12	8.4	10.0	140	150
	11-17-53	9	8.1	2.0	165	167
	12-15-53	5	8.1	0.1	140	140
Omaha, Nebraska	8-21-52	25	8.0	0.0	115	115
	9- 9-52	26	8.25	8.0	146	154
	10-31-52	9	8.2	6.0	157	163
	11- 6-52	8	8.3	8.0	161	169
	11-13-52	6	8.3	8.0	157	165
	11-29-52	2	8.1	2.0	174	176
	12- 8-52	1	8.2	6.0	202	208
	12-22-52	0.5	8.1	6.0	224	230
	12-31-52	0.5	8.0	0.0	235	235
	1-16-53	0.5	8.0	0.0	233	233
	2- 2-53	1.1	8.0	0.0	205	205
	2- 6-53	1.1	8.0	0.0	192	192
	2-23-53	0.5	7.9	0.0	197	197
	3-12-53	2.2	7.6	0.0	189	189
	3-26-53	4.4	7.8	0.0	183	183
	4-10-53	8	8.0	0.0	162	162
	4-23-53	11	7.9	0.0	171	171
	5-11-53	17	7.9	0.0	147	147
	5-30-53	21	8.1	4.0	199	203
	6-13-53	24	7.8	0.0	147	147

Photosynthetic effects upon carbonate concentration were noticeable in the region of clear water below Ft. Randall Dam following recession of the 1953 June rise. Increases in CO_3 were associated with greater algal density (refer to Figure 2), and were accompanied by hydrogen ion decreases--that elevated pH to 8.5--and oxygen supersaturation (Tables 9 and 13).

In 1954, relationships of carbonate to photosynthesis were not as marked as during the latter half of 1953, but were again largely confined to Ft. Randall Reservoir and the river below. In July, a short period of chemical stratification in Ft. Randall Reservoir removed CO_3 alkalinity temporarily from its discharge. Carbonate increases in Garrison Reservoir apparently arose through leaching of newly inundated soils (Table 10).

In 1955, carbonate generally occurred at all stations; and in most instances higher concentrations were associated with plankton populations in the upper density ranges. Carbonate was again augmented by leaching of the floor of Garrison Reservoir, as photosynthesis was uninvolved in most increases that occurred after May. Ft. Randall Reservoir generally exhibited higher CO_3 content than its discharge--a situation arising from some CO_2 production at depths and greater plankton densities in surface waters.

Analysis for carbonate alkalinity was spotty in 1956 and 1957; and paucity of records precludes any detailed discussion. Thermal and/or chemical stratification removed CO_3 from Garrison discharges in January, February, and August, 1956.

Bicarbonate Alkalinity

Bicarbonate originates in flow of water through and over the earth, and is usually produced by the action of carbonic acid upon limestone. In more humid

Table 10.
Summary of Individual Temperature, pH, Alkalinity, and Hardness Measurements
1956

Station	Date	Temp. °C.	pH	CO_3 alk. ppm	HCO_3 alk. ppm	Total alk. ppm	Total Hardness ppm
Yankton, S.D.	1- 6-56						230
	1-17-56						276
	1-19-56	3.0	8.1	4.0	165.0	169.0	
	1-31-56						252
	2-15-56						272
	2-28-56						326
	3- 9-56	4.0	8.3	8.0	191.0	199.0	
	3-15-56						316
	3-29-56						280
	4-11-56						280
	4-22-56	8.0	8.4	5.0	138.5	143.5	
	4-28-56						236
	5- 9-56						248
	5-18-56	13.0	8.3	7.0	141.0	148.0	
	5-24-56						228
	6- 7-56						252
	6- 8-56	20.0	8.3	3.0	145.0	148.0	
	7- 6-56						236
	7- 7-56	21.0	8.3	6.0	161.0	167.0	
	7-18-56						230
	7-20-56	23.0	8.1	6.0	130.0	136.0	
	8- 1-56						188
	8-15-56						172
	8-24-56	24.0	8.2	8.0	118.0	126.0	
	8-29-56						162
	9- 7-56	24.0	8.4	4.0	114.0	118.0	
	9-12-56						166
	9-20-56	22.0	8.1	4.0	121.0	125.0	
	9-26-56						196
	10- 4-56	12.0	8.1	3.0	137.0	140.0	
	10-12-56						224
	10-18-56	-	8.1	4.0	148.0	152.0	
	10-24-56						228
	10-29-56	9.0	8.1	4.0	146.0	150.0	
	11- 7-56						232
	11- 8-56	11.0	8.1	4.0	141.0	145.0	
	11-21-56						220
	11-22-56	8.0	8.1	2.0	138.0	140.0	
	12- 5-56						240
	12- 6-56	3.0	8.2	1.0	139.0	140.0	
	12-19-56						262
	12-20-56	3.0	8.2	4.0	146.0	150.0	
Below Ft. Randall Dam	1-18-56						276
	1-19-56	1.5	8.1	4.0	164.0	168.0	
	2- 1-56						
	2-15-56						302
	3- 1-56						316
	3- 9-56	2.5	8.2	2.0	193.0	195.0	312
	3-16-56						326
	3-29-56						276
	4-12-56						262
	4-22-56	7.0	8.2	3.0	147.5	150.5	
	4-26-56						236
	5-10-56						244
	5-18-56	13.0	8.2	9.0	145.0	151.0	
	5-24-56						228
	6- 7-56						200
	6- 8-56	19.0	8.3	8.0	126.0	134.0	
	6-21-56						232
	7- 6-56						238
	7- 7-56	24.0	8.0	8.0	130.0	139.0	
	7-19-56						200
	7-20-56	25.0	7.8	*0.0	139.0	138.0	
	8- 2-56						180
	8-23-56						164
	8-24-56	24.0	8.2	4.0	105.0	109.0	
	8-30-56						156
	9- 8-56	-	-	4.0	110.0	114.0	
	9-10-56	24.0	-	4.0	118.0	122.0	
	9-13-56						130
	9-21-56	20.0	-	4.0	125.0	129.0	
	9-27-56						200
	10- 3-56	10.0	8.1	4.0	144.0	148.0	
	10-11-56						230
	10-19-56	13.5	8.2	5.0	146.0	151.0	
	10-21-56						232
	10-27-56	13.0	8.1	4.0	133.0	137.0	
	11- 3-56	12.0	8.2	5.0	143.0	148.0	
	11- 8-56						246
	11-19-56	9.0	8.2	4.0	148.0	152.0	
	11-29-56						242
	12- 3-56	6.0	8.2	4.0	140.0	133.0	
	12-13-56						232
	12-16-56	4.5	8.2	4.0	145.0	140.0	
	12-27-56						232
	12-28-56	3.0	8.2	4.0	146.0	133.0	
Ft. Randall Reservoir	1-18-56						262
	2- 1-56						274
	2-15-56						280
	3- 1-56						312
	3- 9-56	2.5	8.2	2.0	193.0	195.0	
	3-16-56						326
	3-29-56						284
	4-12-56						282
	4-22-56	7.0	8.2	3.0	147.5	150.5	
	4-26-56						236
	5-10-56						244
	5-18-56	13.0	8.2	8.0	140.0	148.0	
	5-24-56						230
	6- 7-56						200
	6-21-56						212
	7- 6-56						212
	7- 7-56	26.0	8.2	4.0	135.0	130.0	
	7-19-56						200
	7-20-56	26.0	8.1	4.0	122.0	126.0	
	8- 2-56						168
	8-23-56						164
	8-24-56	25.0	8.2	4.0	105.0	109.0	
	8-30-56						136
	9- 8-56	-	-	4.0	110.0	114.0	
	9-10-56	23.0	-	4.0	112.0	116.0	
	9-13-56						168
	9-21-56	20.0	-	8.0	130.0	126.0	
	9-27-56						202
	10- 3-56	10.0	8.1	4.0	144.0	148.0	
	10-11-56						224
	10-19-56	12.0	8.1	4.0	149.0	133.0	
	10-21-56						232
	10-27-56	13.0	8.1	4.0	131.0	135.0	
	11- 3-56	12.0	8.2	5.0	143.0	148.0	
	11- 8-56						238
	11-19-56	10.0	8.2	4.0	141.0	145.0	
	11-29-56						242
	12- 3-56	5.0	8.2	4.0	144.0	138.0	
	12-13-56						244
	12-16-56	4.5	8.2	4.0	140.0	152.0	
	12-27-56						266
	12-28-56	3.0	8.2	4.0	148.0	133.0	

Station	Date	Temp. °C.	pH	CO_3 alk. ppm	HCO_3 alk. ppm	Total alk. ppm	Total Hardness ppm
Chamberlain, S.D.	1-11-56						
	1-18-56	2.0	8.1	4.0	230.0	234.0	346
	1-28-56						344
	2- 8-56						368
	3- 1-56						276
	3- 8-56	2.5	8.1	2.0	194.0	196.0	
	3-18-56						
	4- 6-56						246
	4-12-56						270
	4-21-56	9.5	8.1	2.0	158.5	160.5	262
	4-27-56						
	5-11-56						212
	5-18-56	18.0	8.7	7.0	112.5	119.5	190
	5-25-56						230
	6- 8-56	20.0	8.2	1.0	138.5	140.5	240
	6-22-56						186
	7- 6-56						178
	7- 8-56	26.0	8.3	6.0	120.0	126.0	
	7-20-56	27.0	8.3	6.0	115.0	121.0	176
	8- 9-56						148
	8-24-56	25.0	8.2	4.0	115.0	119.0	
	8-30-56						216
	9- 9-56	18.0	8.6	6.0	130.0	136.0	
	9-13-56						232
	9-18-56	18.0	8.3	4.0	140.0	144.0	
	9-29-56	13.0	8.1	5.0	149.0	136.0	
	10- 4-56						238
	10-14-56	10.0	8.1	5.0	156.0	161.0	
	10-25-56	10.0	8.2	5.0	155.0	160.0	248
	11- 9-56	7.5	8.1	4.0	153.0	157.0	236
	11-29-56	5.0	8.1	4.0	161.0	165.0	
	12- 1-56						276
	12- 7-56	1.0	8.2	6.0	160.0	166.0	
	12-14-56						
	12-20-56						286
	12-21-56	1.5	8.1	4.0	178.0	182.0	290
Pierre, S.D.	1- 5-56						330
	1-22-56						336
	2- 8-56						340
	2-18-56						262
	3- 6-56						276
	3-19-56						216
	4- 3-56						248
	4-15-56						216
	4-28-56						198
	5-11-56						182
	5-25-56						236
	6- 8-56						186
	6-24-56						178
	7- 3-56						184
	7-31-56						156
	8-11-56						156
	8-15-56						180
	9- 1-56						218
	9-17-56						226
	9-27-56						228
	10-12-56						242
	10-28-56						262
	11- 9-56						250
	12- 6-56						270
	12-16-56						286
Mobridge, S.D.	9-13-56	17.0	8.3	20.0	325.0	345.0	No data available
	10-11-56	13.5	8.1	6.0	155.0	161.0	
	11-15-56	3.0	8.3	14.0	148.0	162.0	
	12-13-56	0.0	8.4	1.0	163.0	164.0	
Mandan, N.D.	7-26-56						128
	8- 9-56						140
	8-22-56						210
	8-27-56	20.0	8.05	1.0	147.5	144.5	
	9- 8-56						200
	9-15-56	15.0	8.3	12.0	127.0	139.0	
	9-28-56						
	10- 6-56						208
	10-13-56	-	8.1	10.0	143.0	153.0	228
	10-18-56						
	10-26-56						228
	11- 3-56	6.0	8.2	8.0	157.0	165.0	236
	11-13-56						-
	11-17-56	5.0	8.2	8.0	151.0	159.0	246
	11-29-56						
	12-13-56						232
	12-15-56	3.0	8.2	12.0	136.0	148.0	238
	12-27-56						254
Below Garrison Dam	7-26-56						178
	8- 9-56						196
	8-22-56						212
	8-26-56	21.0	8.2	5.0	133.0	138.0	
	8-30-56						212
	9-10-56						218
	9-15-56	17.0	8.3	8.0	182.0	190.0	
	9-21-56						212
	9-28-56	16.0	8.1	10.0	154.0	164.0	
	10- 6-56						208
	10-12-56	-	8.1	12.0	148.0	160.0	
	10-18-56						236
	11- 2-56	6.5	8.2	14.0	153.0	167.0	238
	11-15-56						244
	11-16-56	5.0	8.2	10.0	148.0	158.0	
	12- 2-56						230
	12-13-56						242
	12-14-56	1.0	8.2	12.0	149.0	161.0	
	12-27-56						254
Garrison Reservoir	7-26-56						178
	8- 9-56						196
	8-22-56						212
	8-26-56	21.0	8.1	5.0	135.0	138.0	
	8-30-56						212
	9-10-56						218
	9-21-56						212
	9-28-56	16.0	8.1	8.0	155.0	163.0	
	10- 6-56						230
	10-12-56	-	8.1	12.0	148.0	160.0	
	10-18-56						236
	11- 2-56	6.5	8.2	12.0	154.0	166.0	244
	11-15-56						240
	11-16-56	5.0	8.2	12.0	142.0	154.0	
	12- 2-56						252
	12-12-56						244
	12-14-56	0.0	8.2	10.0	150.0	160.0	
	12-27-56						258
Above Garrison Reservoir (Upstream of Sanish, N.D.)	8-30-56	18.5	8.2	4.0	137.0	141.0	
	9-14-56	13.0	8.0	8.0	191.0	199.0	308
	9-28-56	10.0	8.1	10.0	153.0	163.0	308
	10-12-56	13.0	8.1	8.0	151.0	159.0	224
	11- 2-56	6.0	8.2	6.0	165.0	171.0	-
	11-16-56	5.0	8.2	10.0	155.0	165.0	260
	12-14-56	0.0	8.1	6.0	181.0	187.0	300

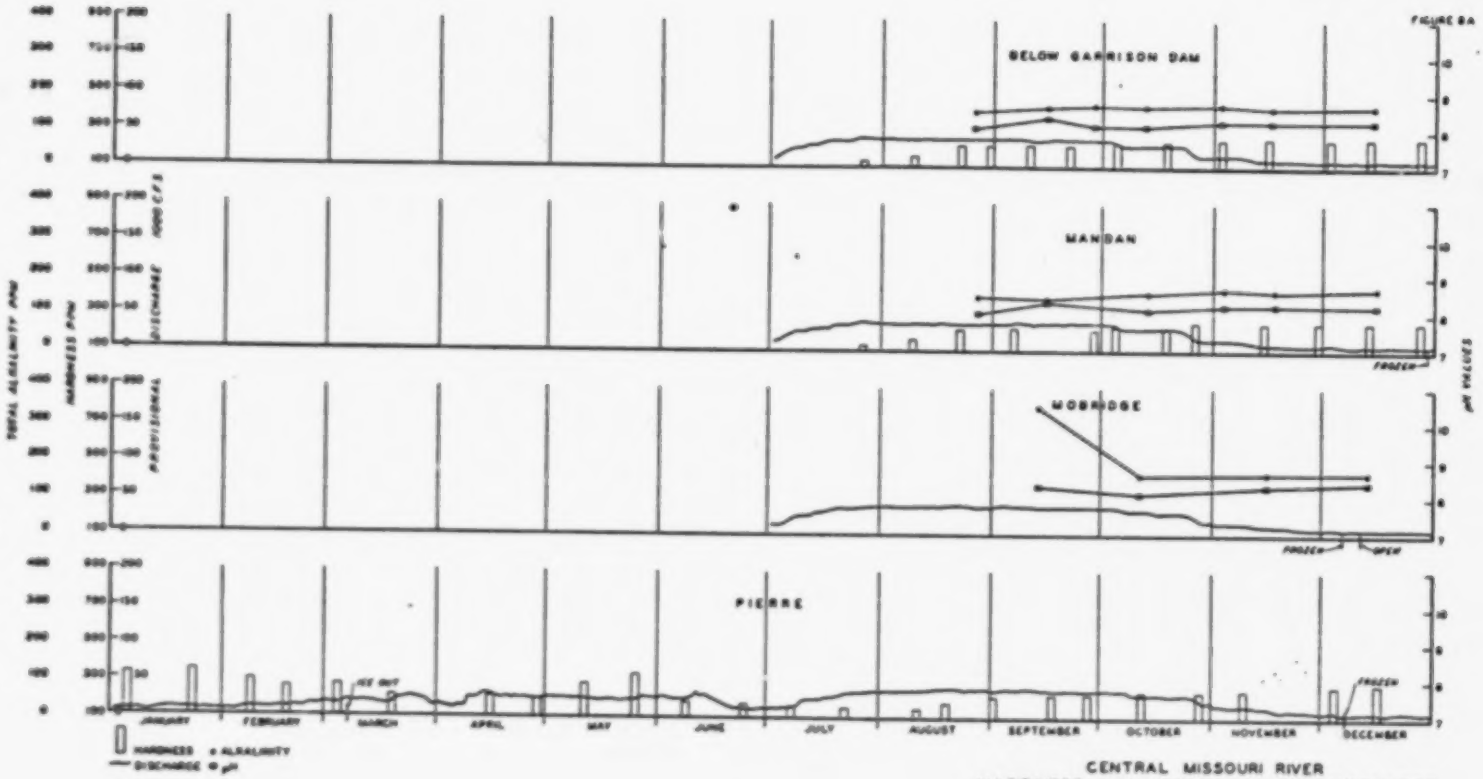
XXXXXXXXXXXXXXXXXXXXXXXX
See the following pages for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXX

Table 10.
Summary of Individual Temperature, pH, Alkalinity, and Hardness Measurements
1954

Station	Date	Temp. °C.	pH	CO_3 Alk. ppm	HCO_3 Alk. ppm	Total Alk. ppm	Total Hardness ppm
Yankton, S.D.	1- 4-54						250
	1-17-54						276
	1-19-54	3.0	8.1	4.0	165.0	169.0	
	1-31-54						282
	3-15-54						272
	3-28-54						326
	3- 9-54	4.0	8.3	8.0	191.0	199.0	
	3-15-54						316
	3-29-54						280
	4-11-54						280
	4-22-54	9.0	8.4	5.0	138.5	143.5	
	4-26-54						236
	5- 9-54						248
	5-18-54	15.0	8.3	7.0	161.0	168.0	
	5-26-54						228
	6- 3-54						202
	6- 8-54	20.0	8.3	3.0	145.0	148.0	
	7- 6-54						234
	7- 7-54	25.0	8.3	6.0	141.0	147.0	
	7-18-54						230
	7-20-54	25.0	8.1	4.0	120.0	124.0	
	8- 1-54						188
	8-15-54						172
	8-24-54	24.0	8.2	8.0	116.0	124.0	
	8-29-54						162
	9- 7-54	24.0	8.4	4.0	114.0	118.0	
	9-12-54						166
	9-20-54	22.0	8.1	4.0	121.0	125.0	
	9-26-54						196
	10- 4-54	12.0	8.1	3.0	137.0	140.0	
	10-10-54						226
	10-18-54	-	8.1	4.0	148.0	152.0	
	10-26-54						228
	10-29-54	9.0	8.1	4.0	146.0	150.0	
	11- 7-54						232
	11- 8-54	11.0	8.1	4.0	141.0	145.0	
	11-21-54						230
	11-22-54	8.0	8.1	2.0	138.0	140.0	
	12- 5-54						240
	12- 6-54	3.0	8.2	1.0	139.0	140.0	
	12-19-54						263
	12-20-54	3.0	8.2	4.0	146.0	150.0	
Below Ft. Randall Dam	1-18-54						276
	1-19-54	1.5	8.1	4.0	164.0	168.0	
	2- 1-54						302
	2-15-54						316
	3- 1-54						312
	3- 9-54	2.5	8.2	2.0	193.0	195.0	
	3-16-54						326
	3-29-54						276
	4-12-54						262
	4-22-54	7.0	8.2	3.0	147.5	150.5	
	4-26-54						238
	5-10-54						244
	5-18-54	13.0	8.2	6.0	145.0	151.0	
	5-26-54						220
	6- 7-54						200
	6- 8-54	19.0	8.5	8.0	126.0	136.0	
	6-21-54						232
	7- 6-54						238
	7- 7-54	26.0	8.0	0.0	139.0	139.0	
	7-19-54						208
	7-20-54	25.0	7.8	0.0	128.0	128.0	
	8- 2-54						188
	8-23-54						164
	8-26-54	24.0	8.2	4.0	105.0	109.0	
	8-30-54						156
	9- 8-54	-	-	4.0	110.0	114.0	
	9-10-54	24.0	-	4.0	118.0	122.0	
	9-13-54						170
	9-21-54	20.0	-	4.0	125.0	129.0	
	9-27-54						206
	10- 5-54	16.0	8.1	6.0	146.0	148.0	
	10-11-54						230
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

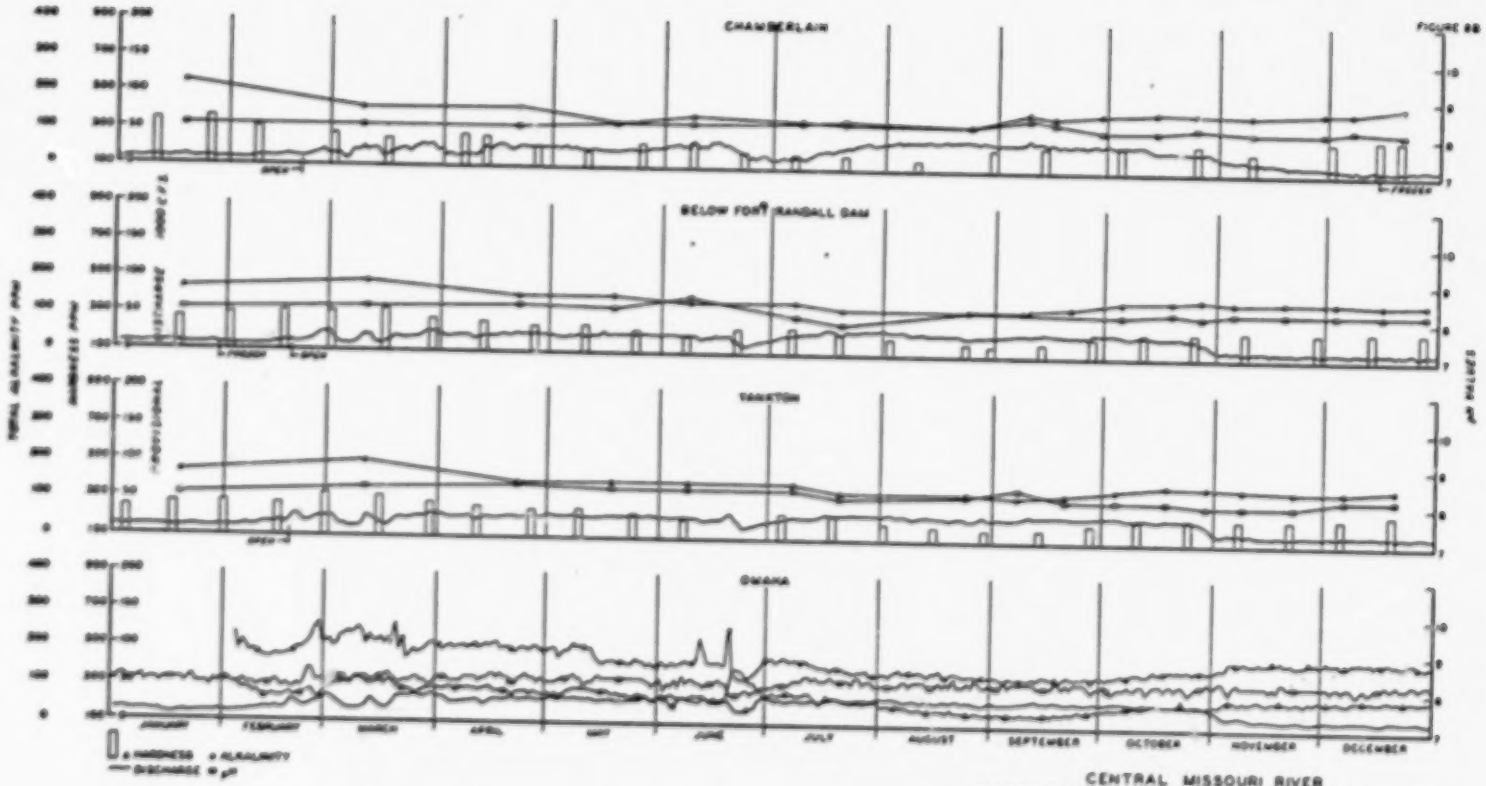
Station	Date	Temp. °C.	pH	CO_3 Alk. ppm	HCO_3 Alk. ppm	Total Alk. ppm	Total Hardness ppm
Chamberlain, S.D.	1-11-54						348
	1-19-54	2.0	8.1	4.0	220.0	224.0	
	1-26-54						304
	2- 8-54						308
	3- 1-54						274
	3- 9-54	2.5	8.1	2.0	154.0	156.0	
	3-16-54						246
	4- 8-54						270
	4-12-54						262
	4-21-54	9.5	8.1	2.0	158.5	160.5	
	4-27-54						212
	5-11-54						190
	5-18-54	19.0	8.2	7.0	112.5	119.5	
	5-25-54						232
	6- 8-54	20.0	8.2	1.0	139.5	140.5	260
	6-22-54						186
	7- 6-54						178
	7- 8-54	20.0	8.3	6.0	120.0	126.0	
	7-20-54	27.0	8.3	6.0	115.0	121.0	174
	8- 9-54						148
	8-24-54	25.0	8.2	4.0	115.0	119.0	
	8-30-54						216
	9- 9-54	18.0	8.4	6.0	150.0	156.0	
	9-13-54						232
	9-18-54	18.0	8.3	4.0	140.0	144.0	
	9-29-54	15.0	8.1	5.0	149.0	154.0	
	10- 4-54						238
	10-14-54	10.0	8.1	5.0	156.0	161.0	
	10-25-54	10.0	8.2	5.0	155.0	160.0	268
	11- 9-54	7.5	8.1	4.0	153.0	157.0	258
	11 29 54	5.0	8.1	4.0	161.0	165.0	
	12- 1-54						276
	12- 7-54	1.0	8.2	6.0	160.0	166.0	
	12-14-54						288
	12-20-54						290
	12-21-54	1.5	8.1	4.0	178.0	182.0	
Pierre, S.D.	1- 5-54						330
	1-23-54						350
	2- 8-54						300
	2-18-54						262
	3- 4-54						276
	3-19-54						214
	4- 3-54						248
	4-15-54						214
	4-28-54						198
	5-11-54						182
	5-25-54						234
	6- 8-54						186
	6-24-54						176
	7- 7-54						166
	7-21-54						159
	8-11-54						150
	8-19-54						180
	9- 1-54						218
	9-17-54						226
	9-27-54						228
	10-12-54						242
	10-28-54						242
	11- 9-54						250
	12- 6-54						276
	12-16-54						284
Mobridge, S.D.	9-13-54	17.0	8.3	20.0	325.0	345.0	
	10-11-54	13.5	8.1	6.0	155.0	161.0	No data
	11-15-54	5.0	8.3	14.0	148.0	162.0	avail-
	12-13-54	0.0	8.4	1.0	183.0	184.0	able
Minden, N.D.	7-28-54						128
	8- 9-54						160
	8-22-54						210
	8-27-54	20.0	8.05	1.0	163.5	164.5	
	9- 8-54						220
	9-15-54	15.0	8.3	12.0	127.0	139.0	
	9-28-54						208
	10- 6-54						228
	10-13-54	-	8.1	10.0	143.0	153.0	
	[illegible]						

Below Ft. Randall Dam	1-18-54						276
	1-19-54	1.5	8.1	4.0	164.0	168.0	
	2- 1-54						302
	2-15-54						316
	3- 1-54						312
	3- 9-54	2.5	8.2	2.0	193.0	195.0	
	3-16-54						326
	3-29-54						276
	4-12-54						262
	4-22-54	7.0	8.2	3.0	147.5	150.5	
	4-26-54						238
	5-10-54						244
	5-18-54	13.0	8.2	6.0	145.0	151.0	
	5-24-54						220
	6- 7-54						200
	6- 8-54	19.0	8.5	8.0	126.0	134.0	
	6-21-54						232
	7- 6-54						238
	7- 7-54	24.0	8.0	0.0	139.0	139.0	
	7-19-54						208
	7-20-54	25.0	7.8	0.0	128.0	128.0	
	8- 2-54						188
	8-23-54						164
	8-24-54	24.0	8.2	4.0	105.0	109.0	
	8-30-54						156
	9- 8-54	-	-	4.0	110.0	114.0	
	9-10-54	24.0	-	4.0	118.0	122.0	
	9-13-54						170
	9-21-54	20.0	-	4.0	125.0	129.0	
	9-27-54						206
	10- 5-54	16.0	8.1	4.0	144.0	148.0	
	10-11-54						230
	10-19-54	13.3	8.2	5.0	146.0	151.0	
	10-25-54						232
	10-27-54	13.0	8.1	4.0	153.0	157.0	
	11- 5-54	12.0	8.2	5.0	143.0	148.0	
	11- 8-54						246
	11-19-54	9.0	8.2	4.0	148.0	152.0	
	11-29-54						242
	12- 3-54	6.0	8.2	4.0	148.0	152.0	
	12-13-54						252
	12-16-54	4.5	8.2	4.0	145.0	149.0	
	12-27-54						252
	12-28-54	3.0	8.2	4.0	148.0	152.0	
Ft. Randall Reservoir	1-18-54						262
	2- 1-54						274
	2-15-54						280
	3- 1-54						312
	3- 9-54	2.5	8.2	2.0	193.0	195.0	
	3-16-54						326
	3-29-54						284
	4-12-54						262
	4-22-54	7.0	8.2	3.0	147.5	150.5	
	4-26-54						236
	5-10-54						244
	5-18-54	13.0	8.3	6.0	142.0	148.0	
	5-24-54						220
	6- 7-54						200
	6-21-54						232
	7- 6-54						232
	7- 7-54	26.0	8.2	4.0	135.0	139.0	
	7-19-54						208
	7-20-54	26.0	8.1	4.0	122.0	126.0	
	8- 2-54						188
	8-23-54						164
	8-24-54	25.0	8.2	4.0	105.0	109.0	
	8-30-54						156
	9- 8-54	-	-	4.0	110.0	114.0	
	9-10-54	23.0	-	4.0	112.0	114.0	
	9-13-54						168
	9-21-54	20.0	-	6.0	120.0	126.0	
	9-27-54						202
	10- 5-54	16.0	8.1	4.0	144.0	148.0	
	10-11-54						224
	10-19-54	12.2	8.1	4.0	149.0	153.0	
	10-25-54						232
	10-27-54	13.0	8.1	4.0	151.0	155.0	
	11- 5-54	12.0	8.2	5.0	143.0	148.0	
	11- 8-54						236
	11-19-54	10.0	8.2	4.0	141.0	145.0	
	11-29-54						242
	12- 3-54	5.0	8.2	4.0	146.0	150.0	
	12-13-54						244
	12-16-54	4.5	8.2	4.0	148.0	152.0	
	12-27-54						244
	12-28-54	3.0	8.2	4.0	148.0	152.0	
	3-29-54						316
	4- 3-54						268
	4-15-54						214
	4-28-54						198
	5-11-54						182
	5-25-54						234
	6- 8-54						186
	6-24-54						176
	7- 7-54						166
	7-21-54						158
	8-11-54						150
	8-19-54						180
	9- 1-54						218
	9-17-54						226
	9-27-54						228
	10-12-54						242
	10-28-54						242
	11- 9-54						250
	12- 4-54						276
	12-16-54						284
Mobridge, S.D.	9-13-54	17.0	8.3	20.0	325.0	345.0	
	10-11-54	13.5	8.1	6.0	155.0	161.0	No data
	11-15-54	5.0	8.3	14.0	148.0	162.0	avail-
	12-13-54	0.0	8.4	1.0	165.0	166.0	able
Mandan, N.D.	7-26-54						128
	8- 9-54						160
	8-22-54						210
	8-27-54	20.0	8.05	1.0	143.5	144.5	
	9- 6-54						220
	9-15-54	15.0	8.3	12.0	127.0	139.0	
	9-28-54						208
	10- 4-54						228
	10-13-54	-	8.1	10.0	143.0	153.0	
	10-18-54						224
	10-26-54						236
	11- 3-54	4.0	8.2	8.0	157.0	165.0	-
	11-15-54						244
	11-17-54	5.0	8.2	8.0	151.0	159.0	
	11-29-54						252
	12-13-54						252
	12-15-54	3.0	8.2	12.0	154.0	166.0	
	12-27-54						254
Below Garrison Dam	7-26-54						128
	8- 9-54						156
	8-22-54						212
	8-26-54	21.0	8.2	5.0	133.0	138.0	
	8-30-54						212
	9-10-54						218
	9-15-54	14.0	8.3	8.0	152.0	160.0	
	9-21-54						212
	9-28-54	14.0	8.1	10.0	154.0	164.0	
	10- 4-54						228
	10-12-54	-	8.1	12.0	148.0	160.0	
	10-18-54						224
	11- 2-54	4.5	8.2	14.0	153.0	167.0	236
	11-15-54						244
	11-16-54	5.0	8.2	10.0	148.0	158.0	
	12- 2-54						250
	12-13-54						243
	12-14-54	1.0	8.2	12.0	149.0	161.0	
	12-27-54						252
Garrison Reservoir	7-26-54						128
	8- 9-54						156
	8-22-54						212
	8-26-54	21.0	8.1	5.0	133.0	138.0	
	8-30-54						212
	9-10-54						218
	9-21-54						212
	9-28-54	14.0	8.1	8.0	155.0	163.0	
	10- 4-54						230
	10-12-54	-	8.1	12.0	148.0	160.0	
	10-18-54						224
	11- 2-54	4.5	8.2	12.0	154.0	166.0	244
	11-15-54						240
	11-16-54	5.0	8.2	12.0	142.0	154.0	
	12- 2-54						252
	12-13-54						244
	12-14-54	0.0	8.2	10.0	150.0	160.0	
	12-27-54						252
Above Garrison Reservoir (Newtown or Sanish, N.D.)	8-26-54	18.5	8.2	4.0	137.0	141.0	
	9-14-54	13.0	8.4	8.0	191.0	199.0	220
	9-28-54	14.0	8.1	10.0	153.0	163.0	228
	10-12-54	13.0	8.1	8.0	151.0	159.0	224
	11- 2-54	4.0	8.2	6.0	165.0	171.0	-
	11-16-54	5.0	8.2	10.0	155.0	165.0	260
	12-14-54	0.0	8.1	6.0	181.0	187.0	300



CENTRAL MISSOURI RIVER
HARDNESS, ALKALINITY, pH AND DISCHARGE
JANUARY - DECEMBER 1954

46.8



CENTRAL MISSOURI RIVER
HARDNESS, ALKALINITY, pH AND DISCHARGE
JANUARY - DECEMBER 1954

40.C

regions it is normally the only form of carbonate entering streams; and CO_3 produced by photosynthesis is at its expense. A soluble monocarbonate also enters the Missouri River; and possibilities exist for a slight augmentation of bicarbonate when CO_2 is produced in the water. However, quantities of HCO_3 so evolved would amount to only 6-10 ppm. at most, and total alkalinity is almost entirely dependent upon HCO_3 from soil drainage.

Bicarbonate concentration tends to vary inversely with rate of flow, as low discharges contain greater percentages of ground water. This relationship is more characteristic of small streams, but it was generally evident in the Missouri, although altered by reservoir regulation (Figures 7 and 8, Table 11). Average concentrations of HCO_3 tend to become greater with downstream distance because of increased entrance of ground water during low flow periods. This pattern was true for the reach Williston to Omaha in 1952 and 1953, but there was considerable variation among some of the intermediate stations (Table 9). Circumstances prevented sampling of all tributaries, but their inflows, either more or less alkaline than the main stem, seemingly induced the variation. Concentration (1952) at Bismarck averaged more than at Chamberlain, and the mean at Ft. Randall was greater than that at Chamberlain or Yankton. The White River enters below Chamberlain, and the Niobrara River above Yankton. During August - December, 1952, alkalinity of the Niobrara was 112 ppm; and its discharge amounted to 6 per cent of that in the Missouri at Yankton. Main stem alkalinity decreased from 163 ppm at Ft. Randall to 156 ppm at Yankton. Niobrara inflow alone would have reduced mean alkalinity to 159 ppm.

In 1954, bicarbonate concentration closely followed the pattern shown for total alkalinity (Table 10, Figure 7), as was still the case in 1955, 1956, and 1957.

Total Alkalinity

Alkalinity over the entire river reach was noticeably influenced by Ft. Peck Reservoir discharges from August to November in 1952 and 1953. Over the period August, 1952 to July, 1953, total alkalinity patterns were quite similar at Chamberlain, Ft. Randall, and Yankton. Rather uniform levels were maintained during periods of high releases from Ft. Peck; a decline occurred at the onset of ice cover; concentration rose during winter low stages; then declined in response to general high water conditions extending through the June rise. Ft. Peck releases (see Figures 3 and 7) depressed alkalinity below the level occurring during the March 1953 rise, but did not bring it down to the concentration evident in June. However, lowered alkalinity resulting from high stages was of relatively short duration, so Ft. Peck releases must be accredited greater alkalinity reduction over this 18-month period.

Ft. Randall Reservoir influences upon alkalinity were first evident in late summer 1953 (Table 9). Concentration below the dam and at Yankton ranged from 140-167 ppm from September to December, and from 118-126 ppm in July and August. Early accumulation of water in the reservoir was at the expense of discharges over a long period, and no build-up of any seasonal runoff occurred (Figure 5). Alkalinity below Ft. Randall Reservoir averaged 17 ppm below that recorded at Chamberlain, the site representative of major flow into the reservoir. Alkalinity reduction within the reservoir was, therefore, due to factors other than dilution by retained surface runoff. Prior to impoundment, alkalinity averaged higher at Ft. Randall than at Chamberlain, hence its decrease within the reservoir was probably of greater magnitude than indicated by measurements at the two stations. Silting may have been responsible for some loss,

Table 11.
Average Total Alkalinity Concentrations
(ppm)

Stations	Above Garrison Reservoir	Below Garrison Dam	Mandan	Bismarck	Mobridge	Above Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha	Council Bluffs
1952										
August							124	104	115	
September							138	135	154	
October							107	105	163	
November							136	104	170	
December							99	96	224	
1953										
January				190		192	198	183	233	
February				175				166	198	
March				169		173	181	150	186	
April				161		150	167	157	167	
May				159		160	163	152	175	
June				122		130	145	126	147	
July				122		137	122	119		
August				152		152	121	147		
September				134		147	144	148		
October				157		154	149	147		
November				171		151	147	167		
December				191		180	143	160		
1954										
January				203		224	168	169		
February				181					175	
March				153		156	195	199	216	
April				151		161	151	144	198	
May				154		120	151	148	182	
June				128		141	134	148	162	
July				123		124	134	136	158	
August		138	145	135		119	109	124	141	
September	181	162	139	155		151	122	122	134	
October	159	160	153	163		161	152	147	151	
November	168	143	162	170		161	150	143	179	
December	187	161	186	178		174	151	145	184	
1955										
January		184	186	191	186	185	153	154	196	
February	170	190	191	201	196	195	157	144	179	
March	153	198	170	203	158	150	163	142	161	
April	119	181	183	197	187	168	168	160	179	
May	156	152	153	164	168	174	158	154	175	
June	122	144	143	157	137	136	160	158	170	
July	135	148	147	156	146	154	149	149	171	
August	156	130	131	141	135	146	154	152	170	
September	160	141	135	140	136	139	144	155	165	
October				134		148	138	138	149	
November	184	160	158	169	154		139	145	161	
December	190	170	173	175	174	183	143	150	168	
1956										
January		172	170	178	171	176	157	150	167	
February		182	183	187	189	187	173	165	178	
March		180	184	172		172	168	156	170	
April	161	182	177	182		167	170	201	181	
May	152	180	177	186	177	179	173	172	151	
June	91	164	165	168	167	175	167	167	162	
July	129	160	156	149	160	153	171	173	175	
August	150	134		132	136	162	163	167	168	
September	155	116		107	123	156	150	158	159	
October	166	112		113	117	160	163	167	156	
November	170	102		121	121	141	133	137	155	
December	183	130		137	134	155	131	136	160	
1957										
January	185	155		153	155	165	154	124	160	149
February	178	168		186	165	163	162	122	154	141
March	152	162		171	166	154	165	131	157	147
April	162	161		176	177	157	152	137	157	160
May	138	156		178	177	171	156	159	173	151
June	108	159		168	176	150	161	155	183	148

Table 11a.
Average Annual Alkalinity Concentrations
(ppm)

Stations	Above Garrison Reservoir	Below Garrison Dam	Mandan	Bismarck	Mobridge	Pierre	Above Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha	Council Bluffs
1953				160			157	147	150		159
1954	169	158	153	158			154	144	145	171	160
1955	150	160	161	166	152		158	153	150	170	161
1956	155	137	167	153	135		154	154	158	165	153
1957	153	160		169	169		159	147	139	163	146

1953 - 6 months' records, January - June, Omaha
1954 - 5 months' records, August - December, Williston and below Garrison
1957 - 6 months records throughout

but photosynthesis by plankton algae resulting in formation of weakly soluble carbonate (CO_3) was apparently the major factor. A slight increase in alkalinity between Ft. Randall and Yankton in 1953 was evidently caused by construction activities at Gavins Point Damsite, as there was no significant change in alkalinity or discharge of the Niobrara River.

In 1954, Ft. Randall Reservoir continued to effect an alkalinity reduction in inflowing water, and average annual alkalinity of its discharge was slightly less than in 1953 (Table 11). Each year it caused an average reduction of 10 ppm, but inflowing water was less alkaline in 1954. In 1955, alkalinity was greater at Chamberlain, and a lesser reduction occurred in the reservoir. No reduction in annual average concentration was realized in 1956; but an average 12 ppm below that at Chamberlain characterized reservoir discharges during the first six months of 1957.

During the period July - December, 1954, Garrison Reservoir discharged water that averaged 11 ppm less in alkalinity than its river inflow. In 1955, however, its releases averaged 10 ppm more than the river above. This increase reflected leaching of minerals from newly inundated soils, and resulted in higher alkalinities at all downstream stations (Table 11). In 1956, the trend was reversed and Garrison discharged less alkaline water than it received from upstream. Yet, during January - June, 1957, it again exerted an alkalinity increase.

Alkalinity at river stations was normally in line with events in the nearest upstream reservoir. Bismarck varied up and down with Garrison releases, although having an annual mean concentration somewhat above the reservoir level (Table 11). Annual averages at Chamberlain remained rather uniform over the period of record. This station was at times within the headwaters of Ft.

Randall Reservoir. Yankton usually differed but little from Ft. Randall discharge on an annual basis, even after closure of Gavins Point Dam.. Omaha and Council Bluffs showed a steady, although slight, decline in annual mean concentration over the period of record. This occurrence indicated that their major alkalinity loads originated in reservoir discharges that served to dilute tributary contributions.

Reduced mean alkalinity concentration arising from a reservoir system may result from dilution afforded by storage of large volumes of surface runoff that previously contributed to high river stages; or, it may represent loss of alkalinity from solution. The latter process may accompany calcium loss to sedimentation of sequestering organic and soil particles or carbonate (CO_3) precipitation by photosynthesis.

Computation of annual alkalinity loads at various stations demonstrated that Ft. Randall Reservoir has consistently reduced the poundage carried in its inflowing water. This fact indicated that quantities of alkalinity had been retained in the reservoir--in solution in stored water, and possibly as a precipitate on the bottom. If decreased load had been brought about solely by retention in stored water, the pounds discharged plus the quantity retained in stored water should just about equal the amount brought into the reservoir. Estimation, on a monthly basis of loads entering, leaving, and remaining in reservoir storage disclosed that the amounts discharged and retained were never equivalent to the quantity carried into the impoundment. Inflowing and discharged loads were based upon the mean monthly concentration of each quantity of water, but the mean concentration of stored water was assumed to be the average of inflow and outflow. This figure was considered more representative of the entire impoundment than routine reservoir measurements from the area

just above the dam, where concentration was usually quite near that of released water.

Most of the time the inflowing load exceeded the total of quantities stored and discharged, but it was sometimes less. When the difference favored the inflowing load, it was assumed to represent the quantity lost to precipitation. When the load entering was less than the total of the other two, the only permissible assumption was that alkalinity had been leached from the reservoir floor. The occurrence of sedimentation and pick-up is shown in Figure 9, which depicts the progressive accumulation of alkalinity on the reservoir floor according to the following method of computation:

a = inflowing load

b = discharged load

c = load retained in theoretical storage

a-(b+c) = X (quantity precipitated (+) or leached from bottom (-)

March 1953 = x^1

April 1953 = x^2

May 1953 = x^3

Etc.

Graph constructed as follows:

March 1953 = x^1

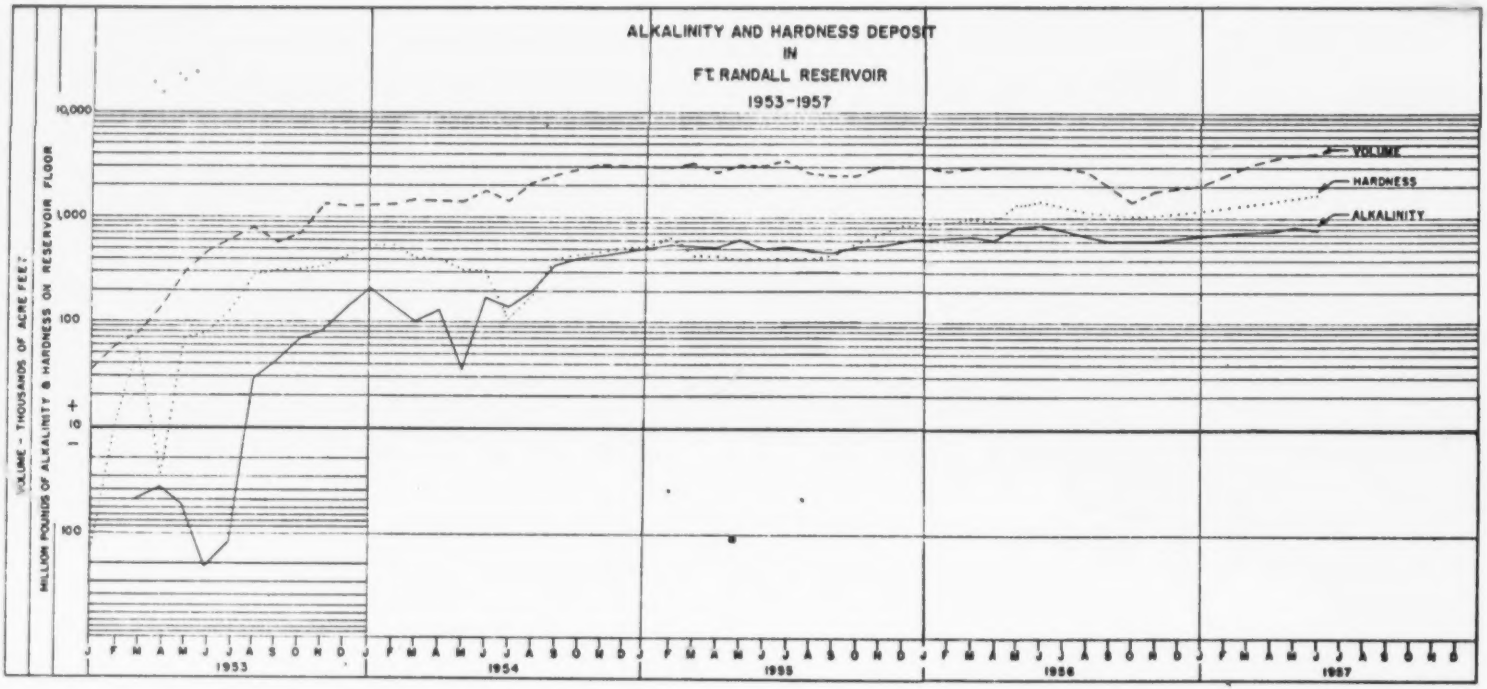
April 1953 = $x^1 \pm x^2$

May 1953 = $x^1 \pm x^2 \pm x^3$

Etc.

Alkalinity was removed from the reservoir site during the period March - July, 1953 (rate declined in April), progressively precipitated from then until

FIGURE 5


ALKALINITY AND HARDNESS DEPOSIT
IN
FT. RANDALL RESERVOIR
1953-1957
VOLUME - THOUSANDS OF ACRE FEET
MILLION POUNDS OF ALKALINITY & HARDNESS ON RESERVOIR FLOOR
10,000
1,000
100
10
100
VOLUME
HARDNESS
ALKALINITY
J F M A M J J A S O N D
1953
1954
1955
1956
1957

45 A

January, 1954, alternately removed and deposited from March - August, 1954, and then built up until leaching of the bottom again occurred in March, 1955. Thereafter, until June, 1957, the trend definitely favored precipitation, although floor accumulations suffered leaching each year. As of June 30, 1957, 765,467,000$\pm$N lbs. of alkalinity removed from inflow were present on the bottom (N = quantity precipitated or leached in November, 1955). A larger quantity (802,302,000 lbs.) rested there on May 30, 1957; and the maximum computed amount (854,070,000 lbs.) was present on June 30, 1956. Over the period March 1, 1953, to June 30, 1957, 29 x 10^9 lbs. of alkalinity were brought into the reservoir, and 2.67% of this load was resting on the bottom, temporarily or permanently removed from solution, on the latter date.

Carbonate precipitation, which accounts for the alkalinity loss in this case, is common in standing bodies of water; and has been responsible for commercially important marl deposits in natural lakes, limestone formations laid down by ancient seas, etc. Limnological studies have shown its occurrence in inland waters to be related to calcium aggregation by sequestering organic particles, and to photosynthetic production of carbonate from bicarbonate ions. The latter process is by far the most important cause of precipitation in the majority of natural waters, and plays a large role in the senescence and eventual death of natural lakes. Transformation of HCO_3 to CO_3 ions occurs in upper layers of water, the photosynthetic zone, whose vertical extent is limited by light penetration. In shallow areas precipitated carbonate usually forms a layer of marl that generally becomes permanent and increases in thickness from year to year. In deeper regions carbonate particles dropping down from the photosynthetic zone may or may not reach the bottom. If thermal stratification or density layers occur, there is an excellent chance that carbon dioxide

will be present in deeper layers, and its reaction with carbonate particles will reconvert them into soluble bicarbonate. Carbon dioxide can also combine with carbonate that has been previously deposited. Either action will increase the alkalinity of deeper waters. In the absence of stratification CO_2 production is much less localized and offers less resistance to carbonate deposition.

Loss of alkalinity from the reservoir floor in 1953 was one expression of mineral leaching from newly inundated soils as water level increased. Precipitation was first noticeable in August of that year, when a high level of photosynthesis was instituted by a dense algal population. Alkalinity deposit continued through January 1954, as did oxygen supersaturation resulting from photosynthesis. In March, the reservoir experienced a sudden increase in alkalinity concentration, evidently from leaching, that offset the influences of algal photosynthesis, which was still producing supersaturated oxygen levels. In April, reservoir concentration once more fell below that of inflowing water and precipitation again occurred. In May, concentration of inflowing water experienced another fall, and the reservoir was credited an alkalinity increase, although its concentration was less than that of April. In June, concentration was below that of inflowing water and deposit was indicated. Leaching was again indicated for July, but progressive deposit characterized the rest of 1954 and January and February, 1955. Alkalinity of discharges was significantly below that of inflow during this period.

Records are inadequate to allow as close estimation of alkalinity deposit or pickup in Garrison Reservoir. Available measurements indicate that leaching exceeded sedimentation by more than 205 x 10^6 lbs. in 1955 (no records January and October), by more than 136 x 10^6 lbs. in 1956 (no records January through March), and by 46 x 10^6 lbs. over the first five months of 1957. In 1955 and 1957, leaching of the reservoir floor resulted in an increase in the average annual

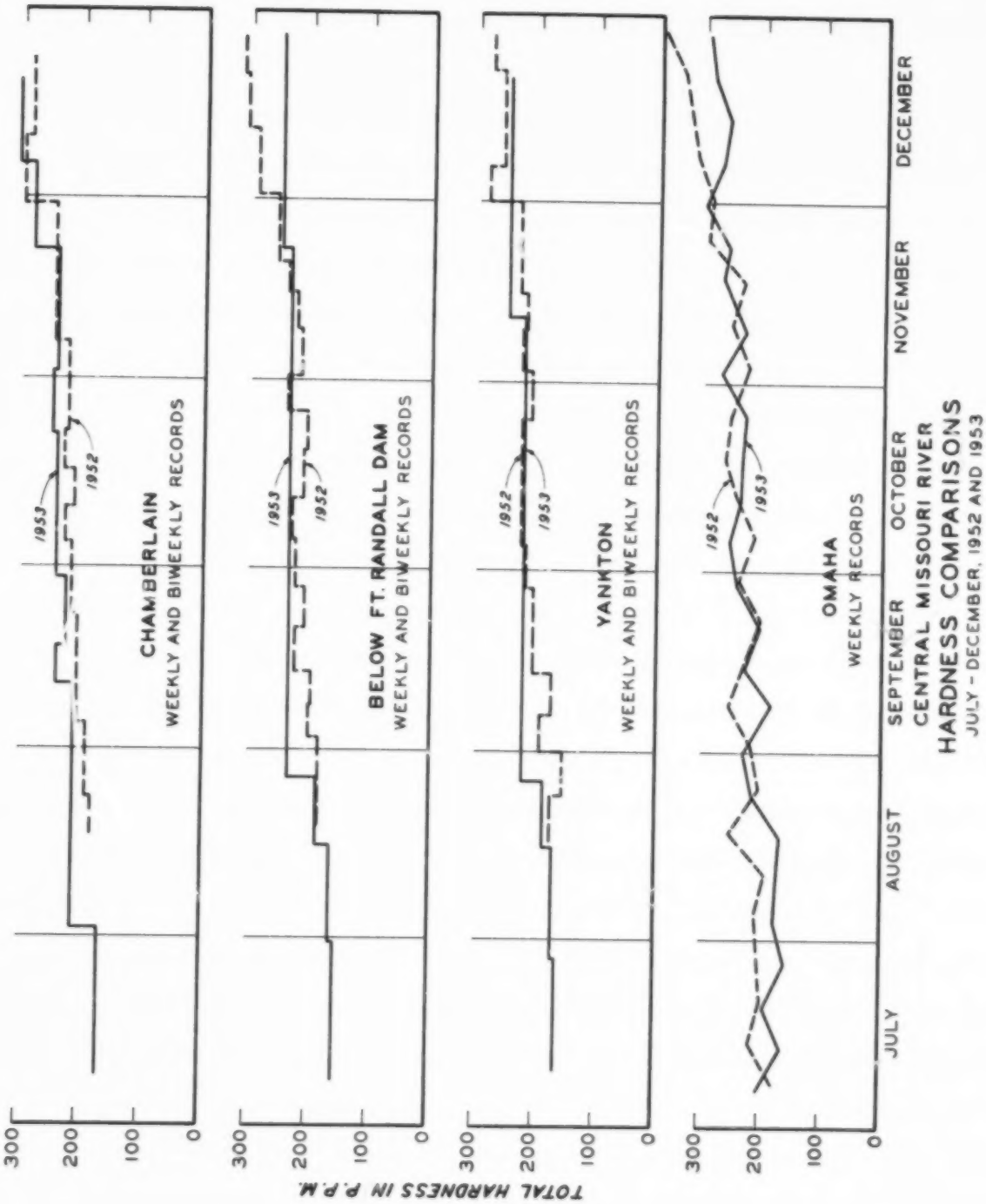
alkalinity concentration; however, this did not occur in 1956 when water releases exceeded inflow over most of the year.

Hardness

Hardness, which may also be caused by iron and manganese, is most commonly due to calcium and magnesium; and, as these two elements usually occur as carbonates and bicarbonates, there is frequently a general correlation between hardness and alkalinity. Wide differences are possible, however, as certain compounds, such as calcium sulfate (gypsum), can add considerable hardness without contributing to alkalinity, and sodium carbonates can add to alkalinity without affecting hardness.

During early months of this study, hardness variation exhibited many similarities to changes in alkalinity--lowest concentrations were related to high discharges and reservoir releases, and maximums occurred during annual low discharges. In 1952 hardness increased when Ft. Peck releases were lowered at the close of the navigation season. Lowest hardness in 1953 followed recession of the June rise, and low concentrations extended into August (Figure 7). Hardness was more concentrated at river stations above Ft. Randall during the last six months of 1953 than during the same period in 1952, yet it averaged less at stations below Ft. Randall Dam in 1953. Hardness was not consistently lower below the reservoir in 1953, but was much more uniform (Figure 10). In 1954, minimum levels in general followed rather closely on the heels of the June rise, a feature characteristic of reservoirs as well as river reaches. Low concentration apparently proceeded in a downstream direction, and its progress was slowed by Ft. Randall Reservoir. This hardness decline was generally accompanied by an alkalinity loss. At Omaha, hardness declined as discharge increased in June. Maximums appeared at all stations during the winter period of low discharge.

FIGURE 10



CENTRAL MISSOURI RIVER
HARDNESS COMPARISONS
JULY - DECEMBER, 1952 AND 1953

Averages for 1954 were significantly below those of 1953 at all stations (Table 12). During August - December, hardness below Ft. Randall Dam averaged 225 ppm in 1953 and 212 ppm in 1954. At Yankton, comparable figures were 222 and 209. These figures are quoted because reservoir conditions did not become established until late summer, 1953. Although its annual mean concentration was lower, Ft. Randall Reservoir discharged harder water than it received during the period March - July, 1954. This occurrence was not unexpected, as mineral leaching from newly inundated soils frequently accompanies rising water levels. Despite this pickup, the reservoir was still able to reduce the average annual concentration and annual hardness load of its inflow. Garrison Reservoir reduced average concentration of its inflow by 30 ppm during the period of record in 1954.

The story of hardness in 1955 was essentially the same as that of alkalinity--namely, it increased in Garrison Reservoir, declined in Ft. Randall, continued its decline at Yankton, and increased at Omaha. Increases in Garrison Reservoir occasioned higher average concentrations down to Chamberlain. Reservoir levels were great enough to further delay the appearance of the annual minimum hardness concentration, which previously closely followed the June rise. In 1954, Ft. Randall slowed the downstream progress of this phenomenon about one month. In 1955, the annual minimum made its appearance in June and July above Garrison, but did not occur in reservoir releases until August and September. Pierre and Chamberlain experienced low concentrations during the same two months, but flow through Ft. Randall Reservoir delayed their appearance at Omaha until October and November. Reservoirs exerted considerably more effect upon native river patterns of fluctuation in mineral content than during previous years. The major influence was exerted by Garrison Reservoir, whose

Table 12.
Average Hardness Concentrations
(ppm)

Stations	Above Garrison Reservoir	Below Garrison Dam	Mandan	Bismarck	Mobridge	Pierre	Above Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha	Council Bluffs
1952											
August						182	185	185	164	189	
September						216	212	208	193	218	
October						243	221	221	220	233	
November						236	235	232	228	253	
December						320	292	306	283	318	
1953											
January				268		359	308	320	308	325	
February				252		307	321	304	300	331	
March				242		325	295	286	265	300	
April				230		290	257	270	250	291	
May				211		274	268	256	287	282	
June				158		218	264	263	164	275	
July				144		156	164	155	184		
August				216			208	176			
September				227				230			
October				226		226	236	234	224		
November				247		250	248	239	221		
December				271		314	302	248	250		
1954											
January				288		340	355	276	269		
February				262		381	308	309	299	291	
March				207		244	260	305	298	293	
April				204		220	248	250	248	273	
May				203		208	211	232	238	260	
June				159		181	213	216	202	220	
July		128	128	152		160	176	223	232	244	
August		193	185	180		165	182	169	174	189	
September	224	212	214	217		224	232	188	181	178	
October	224	226	226	226		242	243	231	226	225	
November	260	240	248	227		250	258	244	231	257	
December	300	248	253	227		280	285	252	252	267	
1955											
January		270		245	272	296	292	249	248	285	
February	250	292		263	288	308	307	259	258	274	
March	212	296		256	268	250	282	266	216	228	
April	218	288		256	264	274	272	275	267	267	
May	222	214		231	229	254	260	267	261	274	
June	177	203		210	207	225	227	268	249	260	
July	186	194		205	200	216	219	231	227	234	
August	223	182		187	180	195	201	228	220	240	
September	240	186		189	180	192	184	206	208	233	
October		228		215	206	211	220	197	194	211	
November	256	241		244	237	236	255	203	200	222	
December	300			248	259	293	289	210	223	236	
1956											
January		257	258	254	259	276	286	241	233	234	
February		276	274	274	268	280	293	252	252	250	
March		281	256	249	232	248	271	255	232	229	
April	258	268	273	265	250	258	258	265	260	252	
May	216	277	266	273	263	279	300	211	219	229	
June	105		248	252	230	257	269	254	245	234	
July	169	215	373	225	212	228	238	263	264	262	
August	208	186	196	196	187	203	217	250	255	253	
September	220	162	163	170	162	181	202	210	232	239	
October	244	155	159	167	156	173	192	198	207	217	
November	252	160	164	168	161	181	191	189	196	215	
December	282	175	173	173	179		206	188	204	220	
1957											
January	282	217	200				225	182	182	215	213
February	268	240	224				244	192	154	205	208
March	258	254	236			232	246	206	167	202	194
April	250	259	247			235	247	207	169	197	185
May	208	233	233			254	253	227	220	219	207
June		232	236			302	264	224	215	229	196

Table 12a.
Average Annual Hardness Concentrations
(ppm)

Stations	Above Garrison Reservoir	Below Garrison Dam	Mandan	Bismarck	Mobridge	Pierre	Above Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha	Council Bluffs
1953						231	271	259	264	261	240
1954	246	216		211		246	247	240	238	244	241
1955	221	235		229	232	226	248	236	232	247	235
1956	216	219	237	222	215	226	242	234	234	237	224
1957	243	239	230			253	245	205	180	211	201

1953 - 6 months' records, January - June, Omaha
1954 - 5 months' records, August - December, Williston and below Garrison
1957 - 6 months' records throughout

storage was markedly augmented in June and July. Ft. Randall storage increased slightly in June and July, but lost volume in August and September.

In 1956, Garrison Reservoir delayed downstream appearance of the annual hardness minimum for five months, June to November. It was delayed another two months by flow through Ft. Randall and Gavins Point Reservoirs and did not reach Yankton, South Dakota, and Omaha, Nebraska, until February and April, respectively, 1957 (Table 12). Below Ft. Randall (includes Yankton and Omaha) maximum or near maximum concentrations occurred in June, July, and August, or when annual minimums appeared prior to or during early stages of impoundment. The natural annual pattern of variation in mineral content was almost completely reversed. In 1957, stations in and below Ft. Randall built up toward another maximum in June or July. During these last two years, both reservoirs smoothed out fluctuations occurring in the river above and stations under their influence generally approached maximums and minimums gradually over a period of a few months.

Hardness deposit upon and leaching from the floor of Ft. Randall Reservoir were computed in the manner described for alkalinity and the progressive accumulation of precipitated hardness also appears in Figure 9. The general similarity of hardness and alkalinity buildup in this figure and parallel regression lines (Figure 11) as developed for 1953 and 1954 indicate that hardness removal was chiefly due to carbonate sedimentation. However, one noteworthy exception occurred: in May, 1954, a sudden increase in alkalinity leaching was not accompanied by a similar hardness loss.

Events responsible for the varying pattern that occurred in 1954 are difficult to ascertain, and its occurrence may possibly indicate the omission

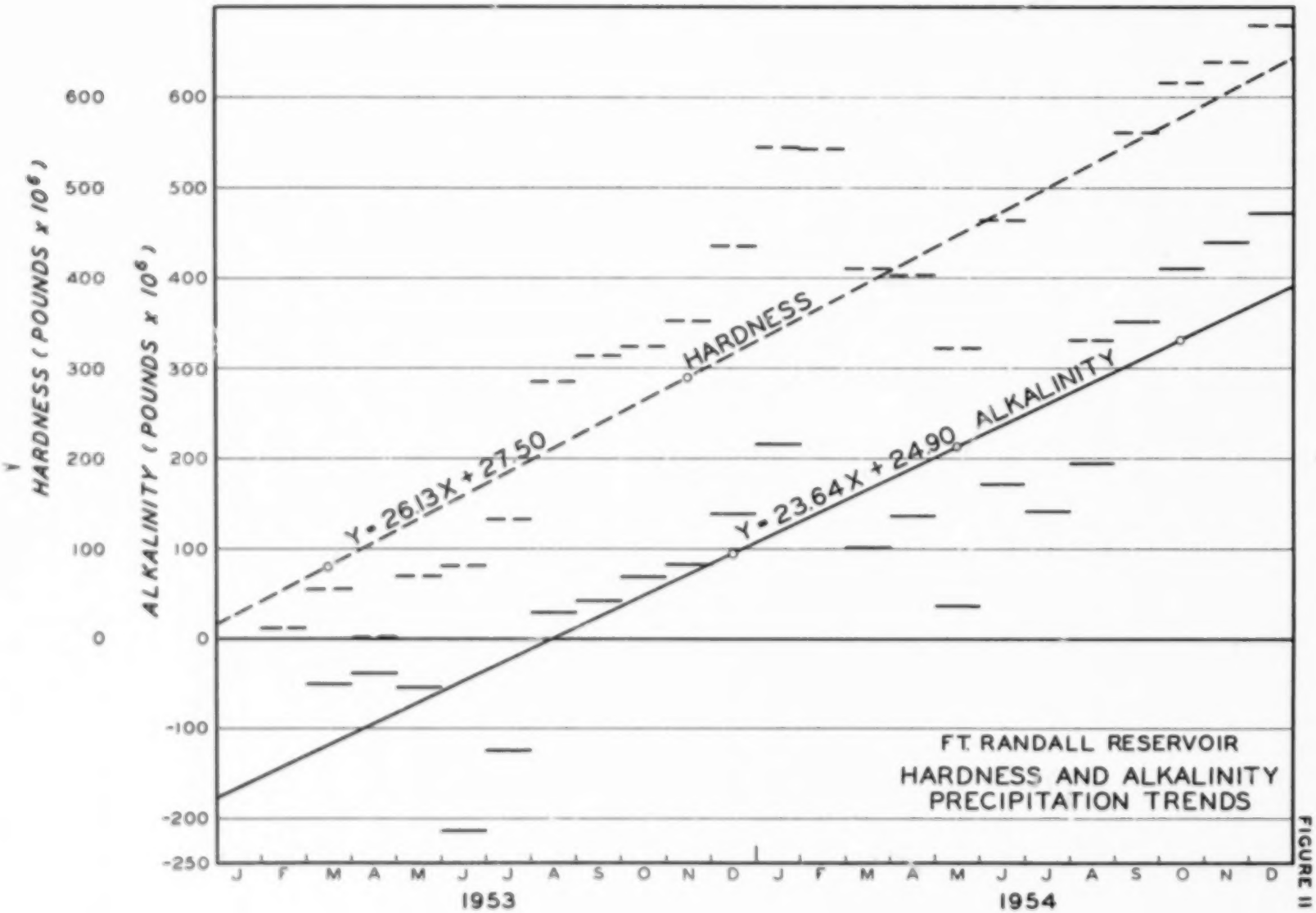


FIGURE 11

51-A

of an obscure factor in this system of computation. However, it is also possible that samples of inflow were not always representative, particularly when the reservoir extended to Chamberlain, and storage time of samples in 1954 was sometimes extended. These possible sources of error argue against seeking a natural explanation; and this exceptional period does not impair the general impression that carbonate precipitation (usually by photosynthesis) is chiefly responsible for hardness and alkalinity sedimentation in the reservoir.

The maximum amount of hardness noted on the reservoir floor, 2×10^9 lbs., rested there on June 30, 1957.

Paucity of records precludes similar computation of hardness load deposited and removed from the bottom of Garrison Reservoir. Nine months' data indicate that 103×10^6 lbs. were leached from the floor in 1955.

Oxygen

Oxygen is supplied to water by absorption from the atmosphere and photosynthesis by aquatic plant life. Rate of absorption from air depends upon a number of factors: air and water temperature: altitude; turbulence; amount of surface exposure per volume of water; per cent of saturation in solution; etc. Oxygen is more soluble in cold water, but warm water conditions usually permit absorption of greater quantities as rate of diffusion is then enhanced. Turbulence that provides air contact with greater surface area per volume increases rate of oxygen absorption. Oxygen is a waste product of photosynthesis, but daily supply by this process is limited to periods of available light. The rate of photosynthesis is controlled by many factors affecting the plants themselves, and it is difficult to anticipate volume of production by this method. In the greater number of instances supersaturations arise through this biological activity.

Oxygen is removed by organic decomposition and respiration of aquatic organisms, and, when supersaturated levels occur, by diffusion to the atmosphere--an action expedited by turbulence. When photosynthetic organisms are absent or inactive, oxygen concentration rarely attains the saturation level. In fact, saturation or supersaturation referable to atmospheric absorption and diffusion usually indicates some rather unusual condition. In most natural waters, regardless of temperature, metabolism of aquatic life usually imposes oxygen demands that are never 100% satisfied by aeration. Metabolic and photosynthetic processes normally make percentage of saturation quite subject to biological control.

Oxygen measurements were initiated in August, 1953, to provide an additional check upon relative photosynthetic activity, as the unrelated occurrence of soluble carbonate could at times mask the usual reactions of pH and alkalinity. At that time it was assumed that supersaturation would be induced by photosynthesis in the majority of cases. Measurements through mid-October, 1953, showed identical supersaturated levels in and below Ft. Randall Reservoir (Table 13) that could justifiably be referred to photosynthesis. Beginning October 29, however, reservoir releases contained more oxygen than the reservoir, which fell below saturation upon one occasion. This difference was unexpected and puzzling until attention was rather forcibly called to air draft to flood control tunnels by the whistling scream of its passage through grated openings. Investigation disclosed that air was entrapped under weight of the discharged water, and solubility of its constituent gases enhanced by being supplied at greater than atmospheric pressures. Entrained air required some distance for release below the dam and, upon three occasions when supersaturated reservoir releases were followed downstream by boat, five miles were

53.4

Table 13.
Summary of Individual Oxygen Analyses % Saturation

Date	Chamberlain	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton
8- 5-53	-	-	122.5	112
9- 1-53	-	102.5	102.5	105
9-15-53	93	104	104	97.5
9-29-53	-	112	112	105
10-13-53	96	102	102	105
10-29-53	-	88	105	100
11-17-53	100	102	117	100
12-15-53	99	108	114	85

required to reduce oxygen content to the saturation level. Supersaturation originating in photosynthesis usually persisted downstream to Yankton. Discharge through flood control tunnels also induced supersaturated oxygen levels below Garrison Dam over the periods indicated in Table 14. However, supersaturations of this nature never extended to Mandan.

Flood control releases did not always induce oxygen supersaturation, and on a few occasions (Table 14) water so discharged was lower in oxygen content than the reservoir above. However, their usual effect was to increase oxygen concentration, and they did this often when supersaturated levels occurred in reservoir water. Discharges through power plants increased oxygen concentration occasionally, but never to the saturation level (Table 14).

During early stages of impoundment (August, 1953 - August, 1954) photosynthetically induced oxygen supersaturation was the usual condition in Ft. Randall Reservoir. This condition generally extended downstream to Yankton, and was occasionally evident at Chamberlain. Yankton samples were usually taken in the early a.m. and are not as representative of photosynthetic effects in 1953 and 1954 as those taken at noon and in the mid-afternoon at Ft. Randall and Chamberlain.

In 1955, supersaturation noted was mainly related to air draft to flood control tunnels. Reservoirs were supersaturated at times, but their mean monthly concentrations were below saturation. Supersaturation was noted in the river only at Mobridge. Yankton samples were collected in the early a.m. and were probably not representative of daily conditions. In 1956, oxygen supersaturation endured for longer periods of time in reservoirs and all sampled river reaches except at Mobridge. Yankton remained supersaturated from January

Table 14.
Average Oxygen Concentration (% Saturation)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Mobridge	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton
1953									
August	-	-	-	-	-	-	-	122*	112*
September	-	-	-	-	-	93*	106	106	103
October	-	-	-	-	-	96*	95	104	103
November	-	-	-	-	-	100*	102*	117*	100*
December	-	-	-	-	-	99*	108*	114*	85*
1954									
January	-	-	-	-	-	97*	-	122*	122*
February	-	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	117*	117*	107*
April	-	-	-	-	-	95*	108*	130*	100*
May	-	-	-	-	-	107*	142*	142*	106*
June	-	-	-	-	-	96*	-	145*	100*
July	-	-	-	-	-	95	102	110	95
August	90*	99*	128*(1)	-	-	100*	103*	102*	102*
September	85	90*	114(1)	92*	86*	97	85	128	97
October	88*	-	-	-	96*	85	77	124	85
November	88	91	122(1)	91	99*	87	99	95	95
December	87*	106*	120*(1)	95*	97*	89	88	88	92
1955									
January	-	89	106(1)	100	88	89	86	97(1)	92
February	76	88	100(1)	98	87	95	90	90(1)	91
March	83	86	99(1)	88	82	87	96	94(1)	91
April	99	99	117(1)	93	104	96	96	125(1)	87
May	96	97	116(1)	96	89	88	98	126(1)	93
June	86	90	124(1)	93	-	85	84	122(1)	92
July	83	85	116(1)	96	92	87	89	124(1)	90
August	86	81	114(1)	89	98	84	81	75(2)	94
September	85	93	120(1)	92	86	80	79	87(2)	88
October	-	-	-	-	-	93	83	79(2)	97
November	96	84	126(1)	91	90	-	93	93(2)	100
December	91	97	117(1)	98	102	95	96	96(2)	98
1956									
January	-	93	120(1)	97	98	88	96	97(2)	115
February	-	84	72(2)	86	81	83	97	93(2)	109
March	-	98	110(1)	95	86	83	96	102(1)	112
April	89	100	97(2)	103	-	108	107	104(2)	108
May	96	104	103(2)	102	97	103	103	102(2)	113
June	80	107	105(2)	101	93	101	100	89(2)	117
July	89	-	-	113	99	94	92	87(2)	112
August	-	-	-	-	-	90	98	98(2)	108
September	-	-	-	-	-	96	89	89(2)	117
October	-	-	-	-	-	96	96	90(2)	121
November	-	-	-	-	-	101	95	90(2)	99
December	-	-	-	-	-	101	91	93(2)	93
1957									
January	-	-	-	-	-	89	92	89(2)	90*
February	-	-	-	-	-	92	99	99(2)	93
March	-	-	-	-	-	93	97	97(2)	109
April	-	-	-	-	-	95	105	103(2)	111
May	-	-	-	-	-	95	101	98(2)	98
June	-	-	-	-	-	94	106*	99*(2)	105*

*Only one record
(1) Flood control discharges
(2) Power plant discharges

through October. In 1956, events in Gavins Point Reservoir replaced Ft. Randall Reservoir effects upon oxygen concentration at Yankton, and supersaturations there were linked with events in Gavins Point. In 1957, oxygen was measured occasionally in the reach Chamberlain-Yankton. Supersaturation was noted at Yankton in March, April, and June; below Ft. Randall Dam in April; in Ft. Randall Reservoir in April, May, and June; and not at all at Chamberlain. Discharge was through the power house only when samples were taken below Ft. Randall Dam. In both 1956 and 1957 supersaturations in and below Ft. Randall were apparently due to photosynthesis. This process was evidently associated with supersaturations also at Mandan, Chamberlain, and Yankton.

Nitrogen

Nitrogen is essential for plant growth. Some blue-green algae have the ability to fix free nitrogen and are at times more or less independent of available nitrogen compounds. However, the majority of Missouri River algae rely upon nitrogen compounds for recourse to this essential element; many are able to use either ammonia or nitrate nitrogen. Organic nitrogen, that tied up in living or dead organic compounds, is not available to algae, but it serves as a general guide to the extent of nitrogen usage and total supply, as it is ultimately converted into available forms. Some green algae (Chlorococcales) show a preference for ammonia nitrogen but are able to use nitrate. Nitrogen is more concentrated in algal bodies than in those of higher plants--a fact that has led to the supposition in some quarters that nitrogen is more important in life processes of algae.

The amount of available nitrogen in water, or soil, is generally dependent upon the outcome of the contest between nitrifying and denitrifying processes, and any level measured must be assumed transitory. Denitrifying organisms

strive to reduce all nitrogen compounds to free N, and oxidation to nitrate (NO_3) is the goal of nitrifiers; intermediate stages are ammonia (NH_3) and nitrite (NO_2) compounds. Nitrite is very transitory and usually occurs where oxidizable forms of organic nitrogen are constantly renewed. It is normally a useful measure to detect zones of faecal contamination, but its presence may not always serve notice of sewage entry, as it is produced at times by concentrations of zooplankters, especially microcrustacea, and other aquatic animals. Where raw sewage discharges promote dense algal growths, nitrite may fail to occur when demands for nitrogen force utilization in the ammonia stage. Ammonia nitrogen is more stable and its compounds may endure for considerable periods of time when biological processes reach a low ebb. It is naturally formed by the breakdown of more complex organic groups, but water-borne quantities can be augmented by various commercial fertilizers applied to soils and discharges from fertilizer factories. Nitrate is the end product of nitrogen oxidation, and in water it develops from simpler or less oxidized nitrogen compounds (NH_3 and NO_2). Quantities are usually present in raw and treated sewage, and it may also reach watercourses from fertilizer application and manufacture.

Small to medium sized streams usually exhibit variation in nitrogen content that is associated with discharge. Certain amounts of these compounds originate in topsoils and some augmentation usually follows a period of rainfall. If constant sources (e.g., sewage discharges, drainage from livestock feeding areas) occur, high discharges normally induce dilution.

Organic Nitrogen

Monthly averages appear in Table 15. In 1952 and 1953, the latter half of the year alone is represented, but the seasonal pattern, with one exception, was almost completely reversed in 1953, and highest concentration brought close

Table 15.
Average Organic Nitrogen Concentration
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Pierre	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton
1952									
August					0.18	0.48		0.17	0.45
September					0.83	0.85		0.41	0.45
October					1.13	0.69		0.74	0.70
November					0.78	0.90		0.94	1.10
December					0.84	0.78		0.88	0.86
1953									
January									
February									
March									
April									
May									
June									
July					1.09	2.30	1.40	1.18	0.84
August						1.75	1.32	0.85	1.75
September							1.34	0.79	
October					1.51	1.37	0.11	0.41	0.92
November					0.05	0.29	0.59	0.30	0.35
December					0.35	0.75	0.17	0.30	0.30
1954									
January					0.14	0.09	0.07	0.07	0.76
February					0.19	0.15	0.06	0.05	0.75
March					0.13	0.07	0.05	0.05	0.03
April					0.06	0.03	0.04	0.03	0.03
May					0.04	0.13	0.03	0.03	0.03
June					0.04	0.09	0.03	0.03	0.06
July					0.72	0.60	0.79	0.53	0.60
August		0.59	0.58	0.68	0.68	0.75	0.81	0.54	0.76
September	0.45	0.36	0.38	0.65	0.74	0.78	0.63	0.65	0.64
October	0.62	0.33	0.31	0.40	1.21	1.00	0.85	0.80	0.76
November	0.96	0.68	0.69	0.56	0.88	0.82	0.58	0.80	1.07
December	0.66	0.79	0.70	0.77	0.80	0.70	0.68	0.77	0.81
1955									
January		0.59	0.60	0.65	0.86	0.74	1.01	0.78	0.80
February	1.10	0.73	0.64	0.65	0.64	0.96	0.57	0.53	0.60
March	0.66	0.94	0.87	1.54	1.26	1.37	1.00	1.01	1.16
April	2.76	1.72	1.80	1.38	0.99	1.18	1.36	1.27	1.24
May	1.31	1.16	1.16	0.84	0.86	0.64	0.64	0.66	0.50
June	2.50	0.70	0.70	1.34	0.94	0.88	0.84	0.78	0.78
July	1.73	0.73	0.79	0.92	1.34	1.16	1.22	1.12	1.15
August	0.58	1.08	1.06	0.69	1.04	1.00	1.02	1.04	0.97
September	0.74	0.84	0.83	1.00	1.22	1.05	0.94	0.96	1.00
October		0.04	0.50	0.60	1.34	1.14	1.12	1.22	1.24
November	0.64	0.67	0.45		1.43	1.19	1.40	1.05	1.20
December	0.86			0.80	1.00	0.88	0.92	0.92	0.91
1956									
January		0.22	0.23	0.36	0.74	0.61	0.58	0.64	0.56
February		0.73	0.72	0.52	0.63	0.69	0.69	0.69	0.80
March		0.65	0.65	0.71	0.75	0.73	0.72	0.80	0.86
April	0.80	0.59	0.56	2.84	0.89	0.76	0.84	0.88	0.97
May	0.91	0.48	0.48	2.26	0.63	0.78	0.68	0.66	0.68
June	1.34			0.48	0.50	0.56	0.45	0.40	0.42
July	0.76	0.67	1.56	0.52	0.35	0.38	0.40	0.82	0.42
August	0.82	0.66	3.72	0.65	0.73	0.44	0.36	0.35	0.51
September	1.54	0.60	0.58	0.63	0.38	0.43	0.70	0.45	1.06
October	0.64	0.66	0.59	0.53	0.28	0.62	0.37	0.30	0.51
November	0.52	0.31	0.29	0.22	0.17	0.13	0.14	0.18	0.16
December	0.31	0.24	0.22	0.38		0.19	0.19	0.19	0.27
1957									
January	0.83	0.58	0.[illegible]9	0.46		0.21	0.28	0.29	0.32
February	0.19	0.53	0.37	0.54		0.46	0.37	0.41	0.50
March	0.69	0.39	0.32	0.61	0.98	0.50	0.40	0.38	0.28
April	0.59	0.20	0.26	0.19	0.14	0.10	0.11	0.30	0.14
May	2.30	0.16	0.12	0.23	0.75	0.62	0.48	0.60	0.30
June		0.56	0.53	0.58	0.91	0.32	0.38	0.49	0.54
July									
August									
September									
October									
November									
December									

Table 15a.
Average Annual Organic Nitrogen Concentration
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Pierre	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton
1952					0.75**	0.74**		0.63**	0.67**
1953					0.75 (SA)	1.29 (SA)	0.99 (SA)	0.64 (SA)	0.83 (SA)
1954	0.72*	0.58**	0.55	0.59**	0.44	0.38	0.35	0.32	0.41
1955	1.36	0.81	0.81	0.96	1.07	0.97	1.01	0.94	0.96
1956	0.84	0.50	0.82	0.84	0.54	0.54	0.52	0.53	0.62
1957	1.00 (SA)	0.40 (SA)	0.31 (SA)	0.40 (SA)	0.62*	0.35 (SA)	0.31 (SA)	0.40 (SA)	0.42 (SA)

* 4-month period
** 5-month period
SA - Semi-Annual

to the middle from near the end of the year. Concentration was very low at most points of record during the first six months of 1954; Yankton alone having substantial levels in January and February. Increase in July characterized all stations and indicated similar events throughout the reach from Pierre to Yankton, not excepting Ft. Randall Reservoir whose organic N content was essentially the same as that of its inflow and discharge. Water in and below Garrison Reservoir was nearly identical over the last five months of 1954, but concentration had significant variation above the reservoir and at Mandan. In 1955, organic nitrogen was markedly more concentrated at all sampled localities. Seasonal variation was greater at and above Mandan than in any lower reach; highest concentration occurred above Garrison Reservoir. This reservoir's influences upon organic nitrogen were not especially noteworthy. Concentration at Mandan frequently deviated considerably from reservoir releases, which often differed from reservoir surface water. Ft. Randall surface and discharge were more alike, and its releases appeared to be the major factor governing concentration at Yankton. Annual average level was greatest above Garrison and lowest in and below that reservoir. Average concentration over the entire sampled reach was 0.99 ppm--a marked increase over the 1954 mean of 0.48 ppm.

In 1956, average concentration over this stretch of river dropped to 0.71 ppm, which represented a decrease at all stations except below Garrison Dam where it remained the same. Although its annual average was lower than in 1955, Mandan experienced its highest recorded concentrations in April and May, 1956. Highest recorded concentration was below Garrison Dam in August. Concentration over the first six months of 1957 was lower than during the first half of 1956 at all stations except Pierre.

Study of Table 15 will disclose that no definite annual pattern became established at any station. Yankton, for example, had high, low, and high

Table 16.
Average Ammonia Nitrogen Concentration
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha	Council Bluffs
1952										
August					0.50		0.40		0.25	
September					0.19		0.09	1.20	0.50	
October					1.10		1.10	0.90	0.15	
November					0.50		0.70	0.70	0.42	
December					0.70		0.70	0.50	0.40	
1953										
January					0.90		0.70	0.50	0.90	
February									0.70	
March					0.50		0.30	0.30	0.40	
April					0.55		0.25	0.55	0.42	
May							0.10	0.05	0.37	
June					0.05		0.05	0.05	0.50	
July					0.00		0.00	0.00		
August					0.05		0.02	0.02		
September					0.00		0.05	0.04		
October					0.10		0.07	0.10		
November					0.05		0.05	0.02		
December					0.10		0.10	0.05		
1954										
January					0.20		0.15	0.15		
February										
March					0.05	0.05	0.05	0.25		
April					0.10	0.20	0.20	0.20		
May					0.05	0.05	0.05	0.15		
June					0.10	0.10	0.10	0.05		
July					< 0.05	0.10	0.13	0.10		
August	<0.10	<0.10	<0.10	<0.10	< 0.05	< 0.10	< 0.10	<0.10		
September	0.10*	<0.10	0.15	0.20	0.25	0.81	0.30	0.35	0.28	
October	<0.10	<0.10	<0.10	0.10	< 0.10	< 0.10	< 0.10	<0.10	0.48	
November	<0.10	<0.10	<0.10	<0.10	< 0.10	< 0.10	< 0.10	<0.10	0.45	
December	<0.10	<0.10	<0.10	<0.10	< 0.10	< 0.10	< 0.10	<0.10	0.49	
1955										
January		0.10	0.10	0.20	< 0.10	0.10	0.20	<0.10		0.55
February	0.10	0.10	0.10	0.20	0.10	0.00	0.00	<0.10		0.42
March	0.10	0.10	<0.10	0.20	0.10	< 0.10	< 0.10	0.15		1.20
April	0.10	<0.10	<0.10	0.10	0.05	0.50	0.50	<0.10		0.55
May	<0.10	<0.10	<0.10	0.10	0.10	< 0.10	0.10	<0.10		0.30
June	<0.05	0.10	0.15	<0.10	< 0.10	0.10	0.15	<0.10		0.50
July	0.10	0.10	0.20	0.15	< 0.10	< 0.10	< 0.10	<0.10		0.41
August	<0.10	<0.10	<0.10	<0.10	< 0.10	< 0.10	< 0.10	0.10		0.32
September	0.40	0.10	0.10	0.10	0.10	0.10	0.10	<0.10		0.38
October					< 0.10	0.15	0.10	<0.10	0.50	0.50
November	0.10	0.10	0.10	0.10		0.10	0.10	0.20		0.41
December	0.40	0.40	0.30	0.20	0.10	0.40	0.40	0.30		0.39
*<0.10										
1956										
January		0.30	0.30	0.30	0.30	0.10	0.40	0.35		0.48
February		0.30	0.40	0.30	0.40	0.30	0.40	0.40	0.14	0.38
March		0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.28	0.58
April	0.20	0.20	0.25	0.20	0.40	0.17	0.23	0.20	0.22	0.55
May	0.20	0.20	0.30	0.20	0.25	0.25	0.25	0.23	0.31	0.48
June	0.15	0.20	0.20	0.25	0.10	0.25	0.25	0.10	0.27	0.52
July	0.10			0.20	0.10	0.10	0.10	0.10	0.24	0.29
August					0.05	0.10	0.10	0.10	0.19	0.39
September					0.22	0.10	0.20	0.12	0.21	0.29
October					0.25	0.20	0.20	0.22	0.11	0.35
November					0.20	0.27	0.27	0.20	0.17	0.35
December					0.20	0.25	0.30	0.30	0.17	0.53
1957										
January					0.32	0.27	0.30	0.40	0.20	
February					0.22	0.25	0.25	0.27	0.22	
March					0.22	0.15	0.22	0.17	0.24	
April					0.12	0.15	0.20	0.20	0.13	
May					0.10	0.20	0.25	0.07	0.18	
June					0.05	0.15	0.30	0.10	0.05	

Table 16a.
Average Annual Ammonia Nitrogen Concentrations
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha	Council Bluffs
1952					0.60		0.60	0.83	0.34	
1953					0.23		0.17	0.13	0.55	
1954	<0.10	<0.10	0.10	0.10	0.10	0.18	0.09	0.10	0.43	
1955	0.12	0.10	0.10	0.12	0.10	0.14	0.15	0.10		0.50
1956		0.25	0.27	0.25	0.21	0.19	0.23	0.19	0.21	0.43
1957					0.17	0.20 (SA)	0.25 (SA)	0.19 (SA)	0.18 (SA)	

levels over the course of 1954, rather uniform concentrations over 1955, and high, medium, high, medium, and low levels in that order during 1956. Below Ft. Randall Dam concentration was low the first half of 1954 and higher the second half, rather uniform over 1955, and high, intermediate, and low during the course of 1956. Annual patterns at other stations may be gained from the table.

Ammonia Nitrogen

In general, this form of nitrogen was more concentrated in 1952 and mid-1953 than in any subsequent year (Table 16). Heavy flooding occurred in the spring of 1952, and it is possible that overflow of lowlands left an organic residue that contributed to ammonia for a while thereafter. Organic nitrogen was not similarly affected, but ammonia increase could arise from breakdown of more complex compounds in or on the soil. Municipal pollution, mostly from northern Omaha, induced substantially higher values at Council Bluffs in 1956 and 1957; Omaha upon occasion had concentrations that seemingly owed their existence to wastes discharged at Sioux City, Blair, and other upstream communities (1953 and 1954).

Nitrite Nitrogen

In 1952 and 1953, nitrite was present only at Williston, Bismarck, and Omaha; in 1954 it was not found at any station; and its occurrence in 1955, 1956, and 1957 is shown in Table 17.

The constant presence of nitrite usually indicates sewage or other organic contamination; if zooplankton is the only source nitrite may be expected to appear and disappear as such populations increase and decrease. Application of these criteria shows that pollution may be blamed for the production of nitrite

Table 17.
Average Nitrite Nitrogen Concentrations
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Mobridge	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha	Council Bluffs
1955											
January		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005
February	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
March	0.005	0.000	0.000	0.010	0.000	0.006	0.000	0.000	0.000	0.005	0.018
April	0.010	0.000	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.003	0.170
May	0.000	0.005	0.002	0.002	0.000	0.000	0.002	0.002	0.002	0.001	0.005
June	0.005	0.005	0.005	0.002	0.005	0.000	0.030	0.018	0.014	0.001	0.008
July	0.000	0.005	0.015	0.001	0.000	0.000	0.030	0.012	0.005	0.004	0.008
August	0.000	0.002	0.002	0.000	0.000	0.002	0.002	0.002	0.000	0.005	0.005
September	0.000	0.000	0.000	0.000	0.000	0.000	0.600	0.000	0.000	0.005	0.004
October						0.000	0.000	0.000	0.000	0.005	0.004
November	0.000	0.005	0.005	0.000	0.000		0.000	0.000	0.000	0.005	0.004
December	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.005
1956											
January		0.000	0.000	0.070		0.005	0.000	0.000	0.000		0.006
February		0.005	0.005	0.000		0.005	0.000	0.000	0.000	0.012	0.005
March		0.000	0.000	0.000		0.005	0.000	0.000	0.000	0.018	0.007
April	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.014	0.007
May	0.002	0.002	0.000	0.000		0.002	0.007	0.007	0.005	0.013	0.007
June	0.002	0.005	0.005	0.002		0.002	0.005	0.005	0.005	0.005	0.004
July	0.000			0.005	0.010	0.002	0.007	0.007	0.000	0.006	0.004
August						0.002	0.005	0.005	0.002	0.008	0.010
September						0.000	0.002	0.002	0.000	0.008	0.003
October						0.000	0.002	0.002	0.000	0.006	0.003
November						0.000	0.000	0.000	0.000	0.003	0.005
December						0.000	0.002	0.002	0.000	0.003	0.004
1957											
January						0.005	0.005	0.002	0.000	0.005	
February						0.005	0.002	0.002	0.000	0.004	
March						0.002	0.000	0.000	0.000	0.006	
April						0.005	0.000	0.000	0.000	0.011	
May						0.005	0.005	0.005	0.000	0.010	
June						0.007	0.000	0.000	0.000	0.029	

Table 17a.
Average Annual Nitrite Nitrogen Concentrations
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Mobridge	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha	Council Bluffs
1955	0.002	0.002	0.002	0.003	0.0004	0.001	0.005	0.003	0.002	0.005	0.007
1956	0.002*	0.002**	0.002**	0.001**		0.002	0.003	0.003	0.001	0.009	0.005
1957						0.005**	0.002**	0.002**	0.000**	0.011**	

* 4-month period
** 6-month period

only at Omaha and Council Bluffs; its sporadic appearance in other localities rather limits its source there to zooplankton. Nitrite production can also be induced by reservoir stratification, but this cannot be claimed for any analysis period of record over the last two and one-half years of this study.

Reappearance of NO_2 in 1955 after its total absence in 1954 seemed to be in response to change in some river condition that had previously suppressed its production even in areas affected by pollutional discharge. Available data allow little insight into factors involved.

Nitrate Nitrogen

Nitrogen in this stage was usually most concentrated in the upper portion of the river reach represented in these samples (Table 18). It seems reasonable to suppose that nitrate was most concentrated where decomposable organic matter was most abundant, but this should also be true of ammonia nitrogen which was often as abundant above and below Ft. Randall Reservoir as it was in the vicinity of Garrison Reservoir. Nitrate is commonly produced in livestock manure, but pastured areas are about equally widespread in South Dakota and North Dakota. Other farming practices in these two States are not as well known to the authors of this report.

The year 1954 was a poor year for nitrate at any station of record; 1955 was considerably better at most stations, as was 1956. The first half of 1957 was characterized by increases above Garrison, in and below Ft. Randall Reservoir, and at Yankton, and by declines at all other stations except Pierre, where concentration remained at the 1956 average. Variation on an annual basis may be gained for each station from Table 18. No marked annual pattern occurred anywhere.

Table 18.
Average Nitrate Nitrogen Concentrations
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Pierre	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha
1952										
January										
February										
March										
April										
May										
June										
July					0.03		0.09	0.09	0.07	0.26
August					0.09		0.07	0.07	0.07	0.11
September					0.09		0.12	0.12	0.11	0.17
October					0.03		0.10	0.10	0.17	0.14
November					0.09		0.15	0.15	0.22	0.05
December										
1953										
January										
February										
March										
April										
May										
June					0.10		0.05	0.05	0.10	
July							0.05	0.05		
August							0.20	0.20	0.10	
September							0.17	0.17	0.10	
October					0.20		0.10	0.10	0.05	
November					0.00		0.10	0.10	0.15	
December										
1954										
January					0.00	0.00*	0.10	0.00	0.05	
February					0.00	0.00	0.00*	0.00	0.10	
March					0.00	0.00	0.00	0.00	0.07	
April					0.07	0.00	0.00	0.00	0.07	
May					0.00	0.00	0.00	0.00	0.00	
June					0.00	0.025	0.45	0.00	0.00	
July		0.08*	0.08*	0.07*	0.00	0.00	0.00	0.00	0.00	
August	*	0.08	0.08	0.06	0.00	0.00	0.00	0.00	0.00	
September	0.16	0.05	0.04	0.08	0.00	0.00	0.00	0.00	0.00	
October	0.17*	0.05	0.05	0.07	0.00	0.00	0.00	0.00	0.00	
November	0.19	0.10	0.11	0.25	0.00	0.00	0.00	0.00	0.00	
December	0.22*	0.07	0.07	0.10	0.00	0.032	0.02	0.03	0.23	
1955										
January		0.07	0.08	0.08	0.02	0.07	0.03	0.41	0.29	
February	0.25	0.12	0.12	0.12	0.04	0.03	0.04	0.03	0.30	
March	0.28	0.22	0.23	0.34	0.02	0.02	0.30	0.02	0.04	
April	0.38	0.26	0.25	0.30	0.20	0.02	0.10	0.02	0.04	
May	0.32	0.42	0.34	0.33	0.30	0.02	0.37	0.02	0.02	
June	0.27	0.34	0.34	0.40	0.16	0.03	0.45	0.03	0.08	
July	0.26	0.28	0.26	0.27	0.12	0.22	0.02	0.30	0.05	
August	0.70	0.24	0.31	0.27	0.04	0.12	0.03	0.18	0.04	
September	0.17	0.21	0.28	0.22	0.09	0.07	0.08	0.07	0.08	
October		0.22	0.22	0.22	0.05	0.09	0.04	0.08	0.03	
November	0.18	0.24	0.27		0.04	0.08	0.05	0.15	0.06	
December	0.32			0.23	0.04	0.08	0.08	0.08	0.06	
1956										
January		0.23	0.27	0.21	0.05	0.03	0.10	0.03	0.12	
February		0.18	0.22	0.23	0.10	0.04	0.14	0.04	0.12	
March		0.21	0.24	0.23	0.40	0.02	0.37	0.03	0.20	
April	0.40	0.24	0.28	0.29	0.12	0.03	0.10	0.03	0.06	
May	0.16	0.27	0.23	0.20	0.05	0.26	0.03	0.26	0.21	
June	0.31			0.28	0.11	0.03	0.17	0.03	0.05	
July	0.24	0.32	0.33	0.21	0.03	0.02	0.22	0.03	0.01	
August	0.19	0.33	0.31	0.32	0.17	0.10	0.06	0.08	0.03	
September	0.27	0.31	0.31	0.22	0.30	0.17	0.09	0.15	0.04	
October	0.11	0.30	0.32	0.16	0.06	0.08	0.11	0.08	0.07	
November	0.02	0.03	0.03	0.01	0.23	0.07	0.28	0.05	0.09	
December	0.08	0.02	0.02	0.04		0.15	0.30	0.15	0.09	
1957										
January	0.15	0.08	0.08	0.08		0.25	0.11	0.25	0.20	
February	0.66*	0.05	0.04	0.09		0.22	0.10	0.22	0.27	
March	0.12	0.03	0.05	0.06	0.20	0.25	0.16	0.25	0.11	
April	0.02	0.06	0.06	0.06	0.20	0.15	0.22	0.15	0.08	
May	0.13	0.04	0.05	0.06	0.10*	0.04	0.17	0.03	0.03*	
June		0.05	0.06	0.05*	0.10	0.04*	0.03*	0.04*	0.02	

Table 18a.
Average Annual Nitrate Nitrogen Concentrations
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Pierre	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha
1952					0.065	0.11		0.11	0.13	0.14
1953					0.10	0.11		0.11	0.10	
1954	0.18	0.07	0.07	0.10	0.006	0.05	0.005	0.0002	0.04	
1955	0.33	0.23	0.24	0.26	0.11	0.12	0.07	0.12	0.11	
1956	0.20	0.22	0.23	0.20	0.15	0.16	0.08	0.08	0.09	
1957	0.24	0.05	0.06	0.07	0.15	0.13	0.16	0.16	0.12	

Phosphorus

Phosphorus is also essential to algal life processes and very small quantities, probably less than minimum measurable amounts in many cases, are capable of promoting significant algal densities. It originates in soil formations (rare), in fertilizers and animal wastes, in faecal matter of aquatic animals, especially waterfowl, and in sewage and waste discharges. Growing use of detergents in recent years has increased phosphate content of domestic sewage and many industrial wastes and these contributions have increased the frequency and extended the range of troublesome algae growths. Phosphate content of small streams has been noted to increase sharply following rains and then almost as quickly disappear (4,5,and 6). These observations indicate that phosphorus usually originates on the surface or in the upper layers of soil when pollutional influences, fertilizers, etc., are not involved. Rapid elimination suggests immediate utilization by aquatic life. Phosphorus appears no more essential to algal affairs than nitrogen, but is usually more critical in natural waters as its sources of supply are considerably more limited.

Phosphate within the analysis range (down to 0.01 ppm) occurred only at Williston and Bismarck (1952 - 1953) and at Council Bluffs. At the latter station, its most likely source was municipal wastes. This analysis was not conducted at Omaha. Its April and May, 1953, concentrations at Bismarck, in all likelihood, originated in surface runoff.

Organic (unavailable) phosphorus occurred at all localities at times sampled (Table 19). Average levels varied from year to year at each locality, but with two exceptions (Yankton, 1954; Pierre, 1957), South Dakota stations showed no significant variation during any year of record. Except above Garrison

Table 19.
Average Total Phosphorus Concentrations
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Pierre	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha
1952										
August					0.00	0.02		0.015	0.015	0.06
September					0.01	0.02		0.024	0.028	0.035
October					0.044	0.024		0.028	0.045	0.012
November					0.23	0.023		0.17	0.14	0.17
December					0.16	0.10		0.07	0.08	0.17
1953										
January					0.20	0.09		0.12	0.10	0.20
February					0.09	0.17		0.15	0.12	0.10
March					0.10	0.09		0.11	0.15	0.10
April					0.10	0.15		0.08	0.06	0.095
May					0.10	0.07		0.08	0.075	0.045
June					0.07	0.08		0.11	0.06	0.06
July					0.03	0.01		0.015	0.03	
August						0.035		0.01	0.03	
September								0.025		
October					0.32	0.032		0.027	0.015	
November					0.025	0.022		0.02	0.025	
December					0.05	0.04		0.03	0.05	
1954										
January					0.078	0.037	0.027	0.010	0.153	
February					0.060	0.030	0.050	0.060	0.060	
March					0.050	0.045	0.080	0.105	0.045	
April					0.070	0.055	0.030	0.053	0.045	
May					0.055	0.080	0.280	0.078	0.353	
June					0.055	0.045	0.040	0.035	0.020	
July					0.028	0.030	0.030	0.033	0.042	
August		0.61	0.65	0.44	0.025	0.030	0.055	0.055	0.050	
September	0.62	0.25	0.23	0.62	0.045	0.025	0.025	0.025	0.030	
October	0.74	0.91	0.39	1.28	0.024	0.024	0.027	0.015	0.032	
November	0.43	0.095	0.085	.56	0.027	0.025	0.025	0.035	0.037	
December	0.050	0.298	0.288	.197	0.030	0.035	0.027	0.025	0.037	
1955										
January		0.028	0.028	0.10	0.18	0.18	0.20	0.24	0.20	
February	0.20	0.09	0.10	0.14	0.21	0.21	0.18	0.18	0.20	
March	0.11	0.08	0.04	0.42	0.24	0.27	0.24	0.18	0.22	
April	1.44	0.08	0.11	0.22	0.17	0.21	0.18	0.25	0.24	
May	0.32	0.20	0.20	0.22	0.22	0.25	0.22	0.21	0.18	
June	0.54	0.17	0.20	0.24	0.22	0.16	0.16	0.15	0.19	
July	0.52	0.06	0.04	0.44	0.16	0.11	0.15	0.15	0.17	
August	0.17	0.10	0.08	0.24	0.30	0.18	0.14	0.16	0.18	
September	0.22	0.72	0.70	0.22	0.25	0.22	0.25	0.27	0.22	
October		0.21	0.22	0.29	0.24	0.21	0.27	0.26	0.24	
November	0.58	0.11	0.16		0.27	0.71	1.12	0.38	0.88	
December	0.47			0.27	0.21	0.28	0.20	0.21	0.22	
1956										
January		0.17	0.15	0.21	0.02	0.02	[illegible].08	0.13	0.20	
February		0.28	0.19	0.18	0.33	0.15	0.02	0.02	0.02	
March		0.16	0.14	0.41	0.02	0.04	0.02	0.23	0.08	
April	1.20	0.12	0.17	0.92	0.02	0.02	0.02	0.11	0.22	
May	1.45	0.80	0.13	0.67	0.13	0.03	0.11	0.04	0.02	
June	3.15			0.75	0.10	0.09	0.03	0.09	0.23	
July	1.27	0.22	0.22	0.75	0.22	0.13	0.11	0.11	0.12	
August	0.88	0.07	0.26	0.23	0.20	0.23	0.26	0.17	0.19	
September	1.21	0.95	0.93	1.13	0.24	0.25	0.34	0.34	0.24	
October	2.83	1.74	1.86	1.98	0.27	0.25	0.23	0.29	0.23	
November	1.47	0.97	1.00	0.83	0.29	0.31	0.26	0.24	0.32	
December	0.32	0.74	0.74	0.60		0.24	0.21	0.67	0.42	
1957										
January	1.09	0.81	0.85	0.85		0.28		0.28	0.34	
February	1.15*	0.85	1.10	1.02		0.29		0.27	0.41	
March	0.47	0.75	0.72	0.92	0.79	0.28		0.28	0.26	
April	1.20	0.76	0.67	0.59	0.77	0.34		0.22	0.24	
May	0.12	0.73	0.80	0.65	0.27*	0.29		0.26	0.24*	
June		0.82	0.82	1.00*	0.32	0.26*		0.26*	0.23	

Table 19a.
Average Annual Total Phosphorus Concentrations
(ppm)

Stations	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Pierre	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Yankton	Omaha
1952					0.089	0.037		0.061	0.062	0.089
1953					0.108	0.072		0.066	0.065	0.103
1954	0.31	0.18	0.14	0.26	0.22	0.20	0.28	0.21	0.37	
1955	0.43	0.22	0.16	0.25	0.22	0.24	0.27	0.24	0.26	
1956	1.76	0.56	0.52	0.74	0.16	0.15	0.14	0.17	0.19	
1957	0.77	0.79	0.83	0.81	0.60	0.27	0.26	0.26	0.29	

Reservoir, North Dakota, reaches had comparable levels in 1953 and 1954; but they all had significantly greater concentrations than South Dakota segments in 1956 and 1957. Annual variation at each sampled station may be gained from Table 19. No consistent pattern characterized any station.

Miscellaneous Chemical Features

Calcium, magnesium, silica, fluoride, sodium, potassium, sulfate, copper, and zinc analyses that were conducted at some stations during the first 11 months of this study (Table 20) were planned to permit additional insight into alkalinity-hardness relationships (if these proved atypical), to evaluate a feature (silica) that could be a limiting factor to diatoms, to check on fluoride variation, and to determine if copper and zinc were sufficiently concentrated to interfere with bacterial activity. Hardness-alkalinity relationships appeared to be of the usual sort, and no discussion of Ca, Mg, Na, K, or sulfate is merited. Silica concentrations noted will impose no limitations on diatom growth, and copper and zinc were insufficiently concentrated to be expected to restrict bacteria. Fluoride variation was rather minor, but uniform concentrations may not be expected at any water intake. Table 20 is included for reference purposes.

Discussion of Chemistry

Chemical changes associated with this reservoir system were largely related to biological developments that followed clarification and to leaching of substances from newly inundated soils in reservoir basins. Floor leaching of hardness and alkalinity was detectable only when it exceeded photosynthetic precipitation, and it must be assumed that leaching added to bicarbonate resources that were measurably reduced by photosynthesis at times in all reservoirs. Conversely, it should be noted that observed effects of leaching would have been more pronounced without photosynthesis. Photosynthetic precipitation soon

gained the upper hand on floor leaching in Ft. Randall Reservoir, but it had not solidified a similar position in Garrison Reservoir when this study was closed in 1957. Duration of detectable bed leaching depends upon the erodable nature of soils within the impoundment area, extent of water level fluctuation during early years of reservoir life, incidence of bottom-set siltation, frequency and duration of chemical stratification, and the density and persistence of plankton growths. Standing bodies of water usually isolate themselves from the original soils of their basins through deposition of organic materials, marl, etc., and such activities may reasonably be expected to bring a halt to leaching of the original bed in Garrison Reservoir. Periodic dissolution of deposited marl could occur over most of the life of the reservoir.

Records at weekly and biweekly intervals appeared adequate to demonstrate normal seasonal variability patterns and changes referable to impoundments. Daily records kept at water plants were more precise in indicating the duration of various events, but months with high, medium, or low concentrations of various dissolved substances were as accurately shown by more widely spaced measurements. Weekly and biweekly measurements also gave annual means that indicated the same events as those computed from daily records.

Delays in the appearance of the annual hardness maxima and minima that were imposed by flow through reservoirs indicated that seasonal discharges largely tended to maintain their individuality, although more gradual approaches to extremes showed that some mixing occurred at the junctions of various flow segments. Homogenization of the varied seasonal waters into a uniform body did not occur, and persistence of longitudinal non-uniformity over the five year period suggests that it may be the norm for this system.

Plankton

Methods of Study

Samples were collected in 8, 12, or 16 ounce bottles and preserved with formalin. Suspended sediment interfered with microscopical analysis, and it was at first mandatory to perform this task with 1 ml. portions of unconcentrated or diluted samples. In the interest of uniformity this method was continued throughout the investigation, although subsequent turbidity reductions would have permitted concentration methods at a number of stations. Consistency of results indicated that unconcentrated samples were superior to concentrates in a number of respects. The latter are, of course, necessary for inclusion of organisms whose concentration is less than 1 per ml. Straight samples usually required coverage of the entire area of the counting chamber, and allowed enumeration of forms observable at magnifications of 200 diameters or less. In 1953, routine samples were supplemented by net concentrates taken when and where turbidity conditions permitted.

In waters containing considerable amounts of inanimate suspended matter it is not possible to determine weight of plankton; and volume may be arrived at only by visual measurement and enumeration under a microscope. Volume may be accurately estimated only for those organisms of uniform geometric form, cylinders, spheres, cubes, etc., and only rough approximations may be assumed for irregularly or inconsistently shaped forms, particularly if there is considerable variation. Volumes so arrived at may be expressed as cubic microns, cubic millimeters, ppm by volume, or as special volumetric units. However, volume or even mass of phytoplankters is not directly correlated with their beneficial and harmful effects upon water quality, as such effects usually

depend upon characteristics with which smaller organisms are often more heavily endowed than a number of their larger associates. Reporting on a volumetric basis involves considerable computation, introduces significant sources of error when irregularly shaped organisms form a large part of the plankton population, and appears to have less utility than a simple listing of numbers of each group per volume of water. Reference to total quantity of plankton is usually no more indicative of water quality relationships than is total dissolved solids in the chemical sense. Early progress reports of this investigation contained computations of volumetric plankton units per ml. as illustrative material, but their inclusion in this report of the complete activity is deemed inadvisable; and density or concentration is expressed as the number of individuals per ml. Total number per unit volume is as indicative of favorable or unfavorable conditions as concentration expressed in volume, as limitations may be imposed by varied rates of metabolism and other life activities.

Phytoplankton

Qualitative Features:

Specific determinations of a large number of organisms were not possible at magnifications up to 200 diameters. Identification of such organisms was accomplished by use of special preparations at higher magnification. Some could not be identified beyond genus, and some were not found in smaller volumes examined at high magnifications. Similar or closely related forms were placed in groups for enumeration at routine magnifications. Designation and composition of various groups appear in Table 21.

The phytoplankton population of the Missouri, like that of most streams, consisted of a mixture of true plankton organisms and displaced benthic (bottom) forms (facultative plankters). Organisms representing the true plankter category

See the following pages for greater detail.

A

B

Species Included
F. construens var bimodus (Ehr.) Grun.
F. Harrisonii var. dubia Grun.
Opephora Martyi Heribaud
A. formosa Hassall*
Centronella reichelti Voigt
Synedra ulna (Nitzsch.) Ehr.
S. ulna var. aequalis (Kuetz.) Hust.
S. affinis Kuetz.
S. affinis var. fasciculata (Kuetz.) Grun
S. amphicephala Kuetz.
S. rumpens Kuetz.
Cerataoneis acus Kuetz.
R. curvata (Kuetz.) Grun.
Pleurosigma delicatulum W. Smith
Gyrosigma acuminatum (Kuetz.) Rabh.
Synedra vaucheriae var. capitellata Grun.
Achnanthes Clevei Grun.
Anomoeoneis sphaerophora (Kuetz.)Pfitzer
Navicula gracilis (Ehr.)(very common)
N. Reinhardtii Grun.
N. bicapitellata Hust.
N. pupula var. capitata Hust.
N. cuspidata Kuetz.
N. cuspidata var. ambigua (Ehr.) Cleve
N. hungarica var. capitata (Ehr.)Cleve
N. cari Ehr.
N. pygmaea Kuetz.
Nitzschia dissipata (Kuetz.) Grun.
Nitzschia amphibia Grun.
Amphora veneta (Kuetz.)
Cymbella tumida (Brebisson) Van Heurck
C. cuspidata Kuetz.
C. turgida (Gregory) Cleve
Gomphonema olivaceum (Lyng.) Kuetz.
G.lanceolatum var. insignis(Greg.)Cleve
G.acuminatum var. trigonocephala(Ehr.)Grun.
Cystopleura argus var. alpestris (Grun.)
Rhopalodia gibba (Ehr.) O. Müll.
Eunotia valida Hust.
Hantzschia amphioxys (Ehr.) Grun.
Nitzschia recta Hantzsch
N. sigma (Kuetz.) W. Smith

Group Name	Species Included
Nitzschia gr. (contd.)	N. sigmoidea (Ehr.) W. Smith
	N. vermicularis (Kuetz.) Grun.
	N. capitellata Hust.
	N. commutata Grun.
	N. tryblionella Hantzsch
	N. acuta Hantzsch.
Cymatopleura	Cymatopleura solea (Brebisson)W.Smith
Surirella	Surirella ovata Kuetz.
	S. robusta Ehr.
Green Algae:	
Volvocales:	
Chlamydomonas gr.	Chlamydomonas spp.*
	Coccomonas sp.*
Pandorina	P. morum (Müll.) Bory*
Eudorina	E. elegans Ehr.*
Pleodorina	P. californica Shaw*
	P. illinoisensis Kofoid*
Tetrasporales:	
Gloeocystis	G. gigas (Kuetz.) Lagerheim*
	G. major Gerneck*
Sphaerocystis	S. Schroeteri Chodat*
Asterococcus	A. limneticus G. M. Smith*
Chlorococcales:	
Pediastrum boryanum	P. boryanum (Turp.) Menaghini*
Pediastrum integrum	P. integrum Rhaegeli*
Pediastrum duplex*	P. duplex var. gracilimum West & West
	P duplex var. reticulatum Lagerheim
	P. duplex var cohaerens Bohlin
Scenedesmus dimorphus	S. dimorphus (Turp.) Kuetz.*
Scenedesmus bijuga	S. bijuga (Turp.) Lagerheim*
Scenedesmus quadricauda	S. quadricauda (Turp.)de Brebisson*
Scenedesmus arcuatus	S. arcuatus Lemmermann*
Ankistrodesmus	A. falcatus (Corda) Ralfs*
Schroederia	S. setigera (Schroed.) Lemmermann*
Closteriopsis	C. longissima var. tropica West & West*
Actinastrum	A. Hantzschii Lagerheim*
Dictyosphaerium	D. pulchellum Wood*
Rarer Forms	
Micractinium pusillum Fresenius*	
Crucigenia rectangularis (A.Braun) Gay*	
Dimorphococcus lunatus A. Braun*	
Planktosphaeria gelatinosa G.M.Smith*	

Group Name	Species Included
Rarer Forms (contd.)	
Tetrastrum staurogeniaeforme (Schroed.) Lemmermann*	
Westella botryoides (W. West) de Wildemann*	
Characium sp.	
Oocystis spp.*	
Tetraedron spp.*	
Lagerheimia wratislaviensis Schroeder*	
Coelastrum cambricum Archer*	
Coelastrum proboscideum Bohlin*	
Chrysophyceae:	
Dinobryon	D. sertularia Ehr.*
Dinoflagellates:	
Ceratium	C. hirundinella (O.F. Müll.) Dujardin*
Euglenophyceae:	
Trachelomonas spp.	T. hispida (Perty)*
	T. volvocina Ehr.*
	Trachelomonas urceolata Stokes*
	Euglena acus Ehr.*
	Euglena acutissima Lemmermann*
	Euglena spp.*
	Phacus spp.*
Diatoms: (contd)	
Cocconeis	Cocconeis pediculus Ehr.

are indicated by asterisks in Table 21--others are facultative plankters originating in benthic growths. The distinction between true and facultative plankters is not one that may be expected to cover various environmental situations, because some forms (e.g., Chlamydomonas, Euglena) are upon occasion greatly concentrated either as benthic or planktonic forms, and sometimes as both. Organisms assigned to the facultative group in the Missouri River attained by far their greatest mass in attached growths in various tributaries, and in the Missouri River below dams.

Plankton records cover a period beginning with unregulated flow below Ft. Peck and ending with virtually complete reservoir control of discharge. Initially, factors related to plankton growth and survival were quite different from what they became with establishment of reservoirs. The following accounts consider these factors in chronological order, beginning in 1952.

In 1952 and 1953, some data were accumulated that allowed comparison of main stem and tributary plankton populations, and made possible observations indicative of the possible origin of main stem phytoplankters. These data were amplified by the 1950 study [1] and records available from previous pollutional surveys (8, 9, and 10). All sources indicated that tributaries, especially with regard to dominant groups, differed widely and maintained individually characteristic plankton populations. In general, feeder streams contained a greater number of species than the main stem, and some of them had as predominant groups forms that were poorly represented in the main stem.

On September 1, 1953, the Niobrara River contained 27 plankton groups with Dictyosphaerium (1,352 per ml) and Scenedesmus dimorphus (327 per ml.) as dominant species. Dominant plankters in the Missouri at Yankton on that

date were Melosira (a) and Cyclotella-Stephanodiscus gr.. Only nine groups were common to both the Niobrara and the Missouri at Yankton, and six of these were also present below Ft. Randall Dam. On September 29, 1953, qualitative relationships between the Niobrara and the Missouri were essentially the same, although the Chlamydomonas and Navicula groups were then predominant in the Niobrara. In September, 1952, predominant plankters in the Yellowstone River (8) were Navicula gr. and Diatoma vulgare. The plankton population in the Big Horn River at that time differed somewhat from that in the Yellowstone. The then dominant forms in the Yellowstone did not predominate at any Missouri River station at any time. Fifty-one different groups composed the Yellowstone phytoplankton population, while 23 groups were the most observed at any Missouri River station during the same period. The 1950 study (1) also demonstrated tributary individuality.

Greater plankton variety in tributaries indicated generally more favorable environments than that offered by the main stem, at least during the greater part of 1952 and 1953. Factors contributing to more favorable plankton conditions in the smaller streams require individual evaluation, but some factors of importance were as follows: turbidity was usually very low for extended periods; great extent of shallow areas permitted more luxuriant bottom growths in many cases; lower discharges allowed local nutrient enrichment to be more effective; current velocity was frequently lower; reservoirs often were influential; waterfowl refuges sometimes offered considerable nutrient enrichment; etc.

Origin of Main Stem Phytoplankters:

Seasonal similarities of dominant plankters in 1952 - 1953 along most of the 1,012.2 mile stretch of the Missouri indicated that conditions therein

resulted in development of a characteristic plankton population. The 1950 investigation (1), which covered a more limited period of time, led to the belief that the Missouri developed no especially distinctive plankton population, but rather that most organisms were introduced by tributaries and had relatively short survival periods in the main stem. This impression was gained from the occurrence of meager plankton densities in the Missouri except below the mouths of certain tributaries, where, in each instance, the greater concentrations were qualitatively characteristic of the nearest upstream tributary. If this condition generally prevailed, the main stem would be expected to exhibit striking qualitative differences in dominant groups at various stations. However, close similarities were evident most of the time, especially in the stretch from Pierre to Omaha.

Phytoplankters found in the Missouri undoubtedly originated in tributaries, but, in view of tributary differences, it appears that no tributary inflow may be credited with any special influence. Predominant organisms in the Missouri were, with five exceptions, either Chlamydomonas or diatoms. The five exceptional instances involved the Gomphosphaeria-Coelosphaerium group upon two occasions at Bismarck and once at Pierre. Gloeocystis once outnumbered any other group at Pierre, and Trachelomonas was once predominant at Bismarck. The sporadic occurrence of the Gomphosphaeria-Coelosphaerium group among dominant classes at Williston, Bismarck, Pierre, and Yankton may have represented local tributary influences similar to those reported for the James and Vermillion Rivers in 1950 (1).

Benthic algal growths, source of most facultative plankters, and common in tributary streams, were very rare or nonexistent in the Missouri prior to formation of Ft. Randall Reservoir. Therefore, occurrence of facultative plankters

in the main stem prior to July, 1953, must be assumed to indicate their general origin in tributaries. This relationship suggests that all groups normally originated in the smaller streams. Establishment of characteristic seasonal populations in the Missouri from a variety of distinctive plankton assemblages from tributaries must necessarily have involved elimination of tributary forms incapable of surviving conditions in the big river. Numerical superiority of any group in any tributary would therefore have only locally influenced the main stem, unless such a group was one of the apparent few with greater tolerance. Survival rate of any introduced group appeared to be low except at certain seasons. Environmental conditions, by virtue of lower turbidity, were improved in certain reaches by Ft. Randall Reservoir.

In final analysis, it would appear that the characteristic seasonal populations noted in the Missouri early in this study resulted from a screening process that permitted survival of only definite groups, no matter what their degree of dominance in tributary situations, or their points of origin. It should be pointed out that tributary differences were mainly involved in dominant groups, since in most instances organisms found in the main stem were represented in tributaries. Through 1953, Ft. Randall Reservoir had little effect upon qualitative aspects of the plankton population. Groups that developed to dominant positions in it and its discharge were also predominant in the river above. Lack of influence along this line probably resulted from a filling procedure that did not allow significant retention of any seasonal runoff.

Seasonal Variation:

Seasonal qualitative variation of predominant forms at each station is summarized in Table 22. In 1952 and 1953, usually one of the three generally

Table 22a Most numerous genera of each station in descending order for each month

	Williston	Bismarck	Pierre	Chamberlain	Ft. Randall	Yankton	Omaha
August 1952		Gomphe.-Cyclo. Frag. crotonensis Synedra gr. Melosira (a)	Melosira (a) Synedra gr.	Cyclo.-Stephano gr. Melosira (a) Frag. crotonensis Synedra gr.	Cyclo.-Stephano. gr. Frag. crotonensis	Cyclo.-Stephano. gr. Frag. crotonensis	Chlamydomonas gr.
September	Synedra Gomphe.-Cyclo. Frag. crotonensis		Melosira (a) Fragilaria crotonensis	Melosira (a) Cyclotella-Stephano. gr. Fragilaria crotonensis	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.	Cyclo.-Stephano. gr Gomphe.-Cyclo. gr. Melosira (a)	Cyclo.-Stephano. gr. Melosira (a) Nitzschia gr.
October	Cyclo.-Stephano. Synedra gr.	Cyclotella-Stephano. Synedra gr.	Gomphe.-Cyclo. Aphanizomenon	Cyclo.-Stephano. gr. Aphanizomenon Asterionella	Melosira (a) Cyclo.-Ste,hano. gr. Synedra gr.	Nitzschia gr. Synedra gr. Melosira (a)	Cyclo.-Ste,hano. gr. Melosira (a) Synedra gr.
November	-	Synedra gr. Cyclo.-Stephano. Navicula gr.	Cyclo.-Stephano. Synedra gr.	Cyclotella-Stephano. gr. Synedra gr. Navicula gr.	Cyclo.-Ste,hano. gr. Synedra. gr. Navicula gr.	Cyclo.-Stephano. gr. Navicula gr. Nitzschia gr.	Cyclo.-Ste,hano. gr. Navicula gr. Nitzschia gr.
December	-	Gomphe-Cyclo. Chlamydomonas	Synedra gr.	Synedra gr. Chlamydomonas	Synedra gr. Coleochaetae gr. Cyclo.-Ste,hano. gr.	Chlamydomonas gr. Cyclo.-Ste,hano. gr. Synedra gr.	Cyclotella (a) Chlamydomonas gr. Synedra gr.
January 1953	-	-	Synedra gr. Chlamydomonas	Chlamydomonas gr. Synedra gr.	Synedra gr. Chlamydomonas gr. Cyclo.-Ste,hano. gr.	Chlamydomonas gr. Synedra gr. Navicula gr.	Chlamydomonas gr. Synedra gr. Euglena spp.
February	Synedra gr.	Synedra gr.	Gloeocystis Chlamydomonas	Chlamydomonas gr. Synedra gr.	Chlamydomonas gr. Synedra gr. Gloeocystis	Chlamydomonas gr. Synedra gr. Nitzschia gr.	Nitzschia gr. Synedra gr. Chlamydomonas gr.
March	-	No dominant organism	Nitzschia gr. Navicula gr.	Nitzschia gr. Synedra gr.	Nitzschia gr.	Chlamydomonas gr. Navicula gr. Nitzschia gr.	Nitzschia gr. Navicula gr.
April	-	-	Asterionella Synedra gr. Nitzschia gr.	Asterionella Synedra gr. Chlamydomonas	Nitzschia gr. Chlamydomonas Synedra gr.	Navicula gr. Nitzschia gr. Synedra gr.	Melosira(a) Synedra gr. Asterionella
May	Chlamydomonas gr. Cyclotella (a) Asterionella	Asterionella Synedra gr.	Asterionella Navicula gr. Diatoma elongatum	Asterionella Navicula gr. Synedra gr.	Asterionella Cyclotella (a) Cyclo.-Ste,hano. gr.	Asterionella Cyclo.-Stephano. gr. Synedra gr.	Asterionella Cyclo.-Stephano. gr. Synedra gr.
June	-	-	-	Nitzschia gr. Synedra gr Navicula gr.	Cyclo.-Ste,hano. gr. Nitzschia gr. Synedra gr.	Cyclotella-Ste,hano.gr. Asterionella Diatoma elongatum	Cyclo.-Stephano. gr. Navicula gr.
July	-	Trachelomonas	Cyclotella-Stephano.	Cyclo.-Stephano. gr.	Cyclo.-Ste,hano.gr. Chlamydomonas gr.	Cyclotella-Stephano gr. Navicula gr.	-
August	-	Chlamydomonas gr.	-	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclotella-Stephano.gr.	-
September	-	-	-	Melosira (a) Synedra gr. Nitzschia gr.	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclotella-Stephano. gr.	-
October	-	-	Synedra gr.	Navicula gr. Cyclo.-Stephano. gr.	Chlamydomonas gr. Melosira (a)	Melosira (a) Navicula gr. Cyclo.-Stephano. gr.	Melosira (a) Cyclo.-Stephano gr. Navicula gr.
November	-	-	Nitzschia gr.	Cyclo.-Stephano. gr. Synedra gr. Nitzschia gr.	Cyclo.-Stephano. gr. Chlamydomonas gr. Navicula gr.	Navicula gr. Melosira (a) Nitzschia gr.	Chlamydomonas gr. Cyclo.-Stephano. gr. Navicula gr.
December	-	-	Navicula gr. Chlamydomonas gr.	Cyclo.-Ste,hano. gr. Chlamydomonas gr.	Chlamydomonas gr. Asterionella	Asterionella Cyclo.-Stephano gr. Chlamydomonas gr.	Chlamydomonas gr. Cyclo.-Stephano. gr. Cyclotella (a)

XXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXX

A

Table 22a Most numerous organisms at each station in descending order for each month

	Williston	Bismarck	Pierre	Chamberlain	Ft. Randall	
August 1952	-	Gompho-Coelo. Frag. crotenensis Synedra gr. Melosira (a)	Melosira (a) Synedra gr.	Cyclo.-Stephano gr. Melosira (a) Frag. crotenensis Synedra gr.	Cyclo.-Stephano. gr. Frag. crotenensis	Cyclo Frag
September	Synedra Gompho-Coelo. Frag. crotenensis	-	Melosira (a) Fragilaria crotenensis	Melosira (a) Cyclotella-Stephano. gr. Fragilaria crotenensis	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.	Cyclo Gompho Melos
October	Cyclo.-Stephano. Synedra gr.	Cyclotella-Stephano. Synedra gr.	Gompho.-Coelo. Aphanizomenon	Cyclo.-Stephano. gr. Aphanizomenon Asterionella	Melosira (a) Cyclo.-Stephano. gr. Synedra gr.	Nitzs Synedr Melos
November	-	Synedra gr. Cyclo.-Stephano. Navicula gr.	Cyclo.-Stephano. Synedra gr.	Cyclotella-Stephano. gr. Synedra gr. Navicula gr.	Cyclo.-Stephano. gr. Synedra. gr. Navicula gr.	Cyclo Navic Nitzs
December	-	Gompho-Coelo. Chlamydomonas	Synedra gr.	Synedra gr. Chlamydomonas	Synedra gr. Chlamydomonas gr. Cyclo.-Stephano. gr.	Chlam Cyclo Synedr
January 1953	-	-	Synedra gr. Chlamydomonas	Chlamydomonas gr. Synedra gr.	Synedra gr. Chlamydomonas gr. Cyclo.-Stephano. gr.	Chlam Synedr Navic
February	Synedra gr.	Synedra gr.	Gloeocystis Chlamydomonas	Chlamydomonas gr. Synedra gr.	Chlamydomonas gr. Synedra gr. Gloeocystis	Chlam Synedr Nitzs
March	-	No dominant organism	Nitzschia gr. Navicula gr.	Nitzschia gr. Synedra gr.	Nitzschia gr.	Chlam Navic Nitzs
April	-	-	Asterionella Synedra gr. Nitzschia gr.	Asterionella Synedra gr. Chlamydomonas	Nitzschia gr. Chlamydomonas Synedra gr.	Navic Nitzs Synedr
May	Chlamydomonas gr. Cyclotella (a) Asterionella	Asterionella Synedra gr.	Asterionella Navicula gr. Diatoma elongatum	Asterionella Navicula gr. Synedra gr.	Asterionella Cyclotella (a) Cyclo.-Stephano. gr.	Asteri Cyclo. Synedr
June	-	-	-	Nitzschia gr. Synedra gr. Navicula gr.	Cyclo.-Stephano. gr. Nitzschia gr. Synedra gr.	Cyclo Asteri Diato
July	-	Trachelomonas	Cyclotella-Stephano.	Cyclo.-Stephano. gr.	Cyclo.-Stephano.gr. Chlamydomonas gr.	Cyclo Navic
August	-	Chlamydomonas gr.	-	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclo.-Stephano. gr.	Melos Cyclo
September	-	-	-	Melosira (a) Synedra gr. Nitzschia gr.	Melosira (a) Cyclo.-Stephano. gr.	Melos Cyclo
October	-	-	Synedra gr.	Navicula gr. Cyclo.-Stephano. gr.	Chlamydomonas gr. Melosira (a)	Melos Navic Cyclo.
November	-	-	Nitzschia gr.	Cyclo.-Stephano. gr. Synedra gr. Nitzschia gr.	Cyclo.-Stephano. gr. Chlamydomonas gr. Navicula gr.	Navic Melos Nitzs
December	-	-	Navicula gr. Chlamydomonas gr.	Cyclo.-Stephano. gr. Chlamydomonas gr.	Chlamydomonas gr. Asterionella	Asteri Cyclo. Chlam

B

...ing order for each month

Bismarck	Pierre	Chamberlain	Ft. Randall	Yankton	Omaha
...Coelo. ...rotenensis ... gr. ... (a)	Melosira (a) Synedra gr.	Cyclo.-Stephano gr. Melosira (a) Frag. crotenensis Synedra gr.	Cyclo.-Stephano. gr. Frag. crotenensis	Cyclo.-Stephano. gr. Frag. crotenensis	Chlamydomonas gr.
	Melosira (a) Fragilaria crotenensis	Melosira (a) Cyclotella-Stephano. gr. Fragilaria crotenensis	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.	Cyclo.-Stephano. gr. Gompho.-Coelo. gr. Melosira (a)	Cyclo.-Stephano. gr. Melosira (a) Nitzschia gr.
...lla-Stephano. ... gr.	Gompho.-Coelo. Aphanizomenon	Cyclo.-Stephano. gr. Aphanizomenon Asterionella	Melosira (a) Cyclo.-Stephano. gr. Synedra gr.	Nitzschia gr. Synedra gr. Melosira (a)	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.
... gr. ...tephano. ... gr.	Cyclo.-Stephano. Synedra gr.	Cyclotella-Stephano. gr. Synedra gr. Navicula gr.	Cyclo.-Stephano. gr. Synedra. gr. Navicula gr.	Cyclo.-Stephano. gr. Navicula gr. Nitzschia gr.	Cyclo.-Stephano. gr. Navicula gr. Nitzschia gr.
...oelo. ...monas	Synedra gr.	Synedra gr. Chlamydomonas	Synedra gr. Chlamydomonas gr. Cyclo.-Stephano. gr.	Chlamydomonas gr. Cyclo.-Stephano. gr. Synedra gr.	Cyclotella (a) Chlamydomonas gr. Synedra gr.
	Synedra gr. Chlamydomonas	Chlamydomonas gr. Synedra gr.	Synedra gr. Chlamydomonas gr. Cyclo.-Stephano. gr.	Chlamydomonas gr. Synedra gr. Navicula gr.	Chlamydomonas gr. Synedra gr. Euglena spp.
... gr.	Gloeocystis Chlamydomonas	Chlamydomonas gr. Synedra gr.	Chlamydomonas gr. Synedra gr. Gloeocystis	Chlamydomonas gr. Synedra gr. Nitzschia gr.	Nitzschia gr. Synedra gr. Chlamydomonas gr.
...mt ...m	Nitzschia gr. Navicula gr.	Nitzschia gr. Synedra gr.	Nitzschia gr.	Chlamydomonas gr. Navicula gr. Nitzschia gr.	Nitzschia gr. Navicula gr.
	Asterionella Synedra gr. Nitzschia gr.	Asterionella Synedra gr. Chlamydomonas	Nitzschia gr. Chlamydomonas Synedra gr.	Navicula gr. Nitzschia gr. Synedra gr.	Rhizosolenia gr. Synedra gr. Asterionella
...lla ... gr.	Asterionella Navicula gr. Diatoma elongatum	Asterionella Navicula gr. Synedra gr.	Asterionella Cyclotella (a) Cyclo.-Stephano. gr.	Asterionella Cyclo.-Stephano. gr. Synedra gr.	Asterionella Cyclo.-Stephano. gr. Synedra gr.
	-	Nitzschia gr. Synedra gr. Navicula gr.	Cyclo.-Stephano. gr. Nitzschia gr. Synedra gr.	Cyclotella-Stephano. gr. Asterionella Diatoma elongatum	Cyclo.-Stephano. gr. Navicula gr.
...monas	Cyclotella-Stephano.	Cyclo.-Stephano. gr.	Cyclo.-Stephano. gr. Chlamydomonas gr.	Cyclotella-Stephano gr. Navicula gr.	-
...mas gr.	-	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclotella-Stephano gr.	-
	-	Melosira (a) Synedra gr. Nitzschia gr.	Melosira (a) Cyclo.-Stephano. gr.	Melosira (a) Cyclotella-Stephano. gr.	-
	Synedra gr.	Navicula gr. Cyclo.-Stephano. gr.	Chlamydomonas gr. Melosira (a)	Melosira (a) Navicula gr. Cyclo.-Stephano. gr.	Melosira (a) Cyclo.-Stephano gr. Navicula gr.
	Nitzschia gr.	Cyclo.-Stephano. gr. Synedra gr. Nitzschia gr.	Cyclo.-Stephano. gr. Chlamydomonas gr. Navicula gr.	Navicula gr. Melosira (a) Nitzschia gr.	Chlamydomonas gr. Cyclo.-Stephano. gr. Navicula gr.
	Navicula gr. Chlamydomonas gr.	Cyclo.-Stephano. gr. Chlamydomonas gr.	Chlamydomonas gr. Asterionella	Asterionella Cyclo.-Stephano gr. Chlaymdomonas gr.	Chlamydomonas gr. Cyclo.-Stephano. gr. Cyclotella (a)

See the following pages for greater detail.

Table 27A. Most Numerous Organisms at Each Station in Descending Order for Each Month

Year 1954	Above Garrison Reservoir	Below Garrison Dam	Mandan	Pierre	Chamberlain	Below Ft. Randall Dam	Yankton	Omaha
January	-	-	-	Gloeocystis Chlamy. gr. Cyclo.-Stephano. gr.	Chlamy. gr. Cyclo.-Stephano. gr. Rhizosolenia	Chlamy. gr. Asterionella Heterotrichales	Asterionella Chlamy. gr.	Chlamy. gr. Cyclo.-Stephano. gr. Asterionella
February	-	-	-	Navicula gr. Chlamy. gr. Trachelomonas	Chlamy. gr. Cyclo.-Stephano. gr. Nitzschia gr.	Asterionella Heterotrichales Chlamy. gr.	Asterionella Diatoma elongatum Synedra gr.	Asterionella Nitzschia gr. Cyclo.-Stephano. gr.
March	-	-	-	Chlamy. gr. Trachelomonas	Chlamy. gr. Nitzschia gr. Cyclo.-Stephano. gr.	Asterionella Diatoma elongatum Synedra gr.	Asterionella Diatoma elongatum Synedra gr.	Asterionella Nitzschia gr. Synedra gr.
April	-	-	-	Cyclo.-Stephano. gr. Chlamy. gr.	-	Diatoma elongatum Synedra gr. Asterionella	Diatoma elongatum Synedra gr. Asterionella	Diatoma elongatum Asterionella Synedra gr.
May	-	-	-	Cyclo.-Stephano. gr. Anabaena Trachelomonas	Asterionella Cyclo.-Stephano gr. Synedra gr.	Synedra gr. Asterionella Diatoma elongatum	Synedra gr. Asterionella Diatoma elongatum	Synedra gr. Asterionella Diatoma elongatum
June	-	-	-	Asterionella Cyclo.-Stephano. gr. Rhizosolenia	Asterionella Cyclo.-Stephano. gr. Oscillatoria gr.	Cyclo.-Stephano. gr. Synedra gr. Asterionella	Cyclo.-Stephano. gr. Synedra Asterionella	Cyclo.-Stephano. gr. Synedra gr. Asterionella
July	-	Euglena spp. Aphanizomenon Schroederia	Aphanizomenon Schroederia Nitzschia gr.	Asterionella Melosira (a) Cyclo.-Stephano. gr.	Asterionella Cyclo.-Stephano. gr. Melosira (a)	Cyclo.-Stephano. gr. Melosira (a) Nitzschia gr.	Cyclo.-Stephano. gr. Gloeocystis Cymbella	Cyclo.-Stephano. gr. Rhizosolenia gr. Navicula gr.
August	Oocystis gr. Navicula gr. Rhizosolenia gr.	Cyclo.-Stephano. gr. Euglena spp. Aphanizomenon	Asterionella Cyclo.-Stephano. gr. Aphanizomenon	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stephano. gr. Asterionella Gloeocystis	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.	Cyclo.-Stephano. gr. Melosira (a) Dictyosphaerium	Cyclo.-Stephano. gr. Melosira (a) Nitzschia gr.
September	Navicula gr. Cyclo.-Stephano. gr. Rhizosolenia gr.	Cyclo.-Stephano. gr. Stichococcus Gloeocystis	Cyclo.-Stephano. gr. Asterionella Stichococcus	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.	Cyclo.-Stephano. gr. Melosira (a) Navicula gr.	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.
October	Nitzschia gr. Asterionella Frag. crot.	Asterionella Cyclo.-Stephano. gr. Stichococcus	Stichococcus Asterionella Cyclo.-Stephano. gr.	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stephano. gr. Asterionella Nitzschia gr.	Sphaerocystis Gloeocystis Cyclo.-Stephano. gr.	Navicula gr. Cyclo.-Stephano. gr. Stichococcus	Nitzschia gr. Cyclo.-Stephano. gr. Closteriopsis
November	Navicula gr. Nitzschia gr. Asterionella	Asterionella Cyclo.-Stephano. gr. Gloeocystis & Stichococcus	Asterionella Cyclo.-Stephano. gr. Navicula gr.	Asterionella Cyclo.-Stephano. gr. Gloeocystis & Navicula gr.	Asterionella Cyclo.-Stephano. gr. Chlamy. gr.	Nitzschia gr. Diatoma vulgare Crucigenia	Navicula gr. Crucigenia Rhizosolenia	Rhizosolenia Nitzschia gr. Fragilaria spp.
December	Ankistrodesmus Cyclotella (a) Rhizosolenia gr.	Asterionella Euglena spp. Crucigenia	Asterionella Chlamy. gr. Crucigenia	Asterionella Gloeocystis Euglena spp.	Asterionella Chlamy. gr. Gloeocystis	Rhizosolenia Cyclo.-Stephano. gr. Gloeocystis	Cyclo.-Stephano. gr. Navicula gr. Fragilaria spp.	Cyclo.-Stephano. gr. Nitzschia gr. Chlamy. gr.

A

Table 22b. Most Numerous Organisms at Each Station in Descending Order for Each Month

Year 1954	Above Garrison Reservoir	Below Garrison Dam	Mandan	Pierre	Chamberla
January	-	-	-	Gloeocystis Chlamy. gr. Cyclo.-Stephano. gr.	Chlamy. gr. Cyclo.-Stepha Rhizosolenia
February	-	-	-	Navicula gr. Chlamy. gr. Trachelomonas	Chlamy. gr. Cyclo.-Stepha Nitzschia gr.
March	-	-	-	Chlamy. gr. Trachelomonas	Chlamy. gr. Nitzschia gr. Cyclo.-Stepha
April	-	-	-	Cyclo.-Stephano. gr. Chlamy. gr.	-
May	-	-	-	Cyclo.-Stephano. gr. Surirella Trachelomonas	Asterionella Cyclo.-Stepha Synedra gr.
June	-	-	-	Asterionella Cyclo.-Stephano. gr. Rhizosolenia	Asterionella Cyclo.-Stepha Oscillatoria
July	-	Euglena spp. Aphanizomenon Schroederia	Aphanizomenon Schroederia Nitzschia gr.	Asterionella Melosira (a) Cyclo.-Stephano. gr.	Asterionella Cyclo.-Stepha Melosira (a)
August	Gyrosigma gr. Navicula gr. Rhizosolenia gr.	Cyclo.-Stephano. gr. Euglena spp. Aphanizomenon	Asterionella Cyclo.-Stephano. gr. Aphanizomenon	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stepha Asterionella Gloeocystis
September	Navicula gr. Cyclo.-Stephano. gr. Rhizosolenia gr.	Cyclo.-Stephano. gr. Stichococcus Gloeocystis	Cyclo.-Stephano. gr. Asterionella Stichococcus	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stepha Asterionella Navicula gr.
October	Nitzschia gr. Asterionella Frag. crot.	Asterionella Cyclo.-Stephano. gr. Stichococcus	Stichococcus Asterionella Cyclo.-Stephano. gr.	Cyclo.- Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stepha Asterionella Nitzschia gr.
November	Navicula gr. Nitzschia gr. Asterionella	Asterionella Cyclo.-Stephano. gr. Gloeocystis & Stichococcus	Asterionella Cyclo.-Stephano. gr. Navicula gr.	Asterionella Cyclo.-Stephano. gr. Gloeocystis & Navicula gr.	Asterionella Cyclo.-Stepha Chlamy. gr.
December	Ankistrodesmus Cyclotella (a) Rhizosolenia gr.	Asterionella Euglena spp. Crucigenia	Asterionella Chlamy. gr. Crucigenia	Asterionella Gloeocystis Euglena spp.	Asterionella Chlamy. gr. Gloeocystis

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Month

Mandan	Pierre	Chamberlain	Below Ft. Randall Dam	Yankton	Omaha
-	Gloeocystis Chlamy. gr. Cyclo.-Stephano. gr.	Chlamy. gr. Cyclo.-Stephano. gr. Rhizosolenia	Chlamy. gr. Asterionella Heterotrichales	Asterionella Chlamy. gr.	Chlamy. gr. Cyclo.-Stephano. gr. Asterionella
-	Navicula gr. Chlamy. gr. Trachelomonas	Chlamy. gr. Cyclo.-Stephano. gr. Nitzschia gr.	Asterionella Heterotrichales Chlamy. gr.	Asterionella Diatoma elongatum Synedra gr.	Asterionella Nitzschia gr. Cyclo.-Stephano. gr.
-	Chlamy. gr. Trachelomonas	Chlamy. gr. Nitzschia gr. Cyclo.-Stephano. gr.	Asterionella Diatoma elongatum Synedra gr.	Asterionella Diatoma elongatum Synedra gr.	Asterionella Nitzschia gr. Synedra gr.
-	Cyclo.-Stephano. gr. Chlamy. gr.	-	Diatoma elongatum Synedra gr. Asterionella	Diatoma elongatum Synedra gr. Asterionella	Diatoma elongatum Asterionella Synedra gr.
-	Cyclo.-Stephano. gr. Surirella Trachelomonas	Asterionella Cyclo.-Stephano gr. Synedra gr.	Synedra gr. Asterionella Diatoma elongatum	Synedra gr. Asterionella Diatoma elongatum	Synedra gr. Asterionella Diatoma elongatum
-	Asterionella Cyclo.-Stephano. gr. Rhizosolenia	Asterionella Cyclo.-Stephano. gr. Oscillatoria gr.	Cyclo.-Stephano. gr. Synedra gr. Asterionella	Cyclo.-Stephano. gr. Synedra Asterionella	Cyclo.-Stephano. gr. Synedra gr. Asterionella
anizomenon roederia zschia gr.	Asterionella Melosira (a) Cyclo.-Stephano. gr.	Asterionella Cyclo.-Stephano. gr. Melosira (a)	Cyclo.-Stephano. gr. Melosira (a) Nitzschia gr.	Cyclo.-Stephano. gr. Gloeocystis Cymbella	Cyclo.-Stephano. gr. Rhizosolenia gr. Navicula gr.
erionella lo.-Stephano. gr. anizomenon	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stephano. gr. Asterionella Gloeocystis	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.	Cyclo.-Stephano. gr. Melosira (a) Dictyosphaerium	Cyclo.-Stephano. gr. Melosira (a) Nitzschia gr.
lo.-Stephano. gr. erionella hococcus	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.	Cyclo.-Stephano. gr. Melosira (a) Navicula gr.	Cyclo.-Stephano. gr. Melosira (a) Synedra gr.
hococcus erionella lo.-Stephano. gr.	Cyclo.- Stephano. gr. Asterionella Navicula gr.	Cyclo.-Stephano. gr. Asterionella Nitzschia gr.	Sphaerocystis Gloeocystis Cyclo.-Stephano. gr.	Navicula gr. Cyclo.-Stephano. gr. Stichococcus	Nitzschia gr. Cyclo.-Stephano. gr. Closteriopsis
erionella lo.-Stephano. gr. icula gr.	Asterionella Cyclo.-Stephano. gr. Gloeocystis & Navicula gr.	Asterionella Cyclo.-Stephano. gr. Chlamy. gr.	Nitzschia gr. Diatoma vulgare Crucigenia	Navicula gr. Crucigenia Rhizosolenia	Rhizosolenia Nitzschia gr. Fragilaria spp.
erionella my. gr. igenia	Asterionella Gloeocystis Euglena spp.	Asterionella Chlamy. gr. Gloeocystis	Rhizosolenia Cyclo.-Stephano. gr. Gloeocystis	Cyclo.-Stephano. gr. Navicula gr. Fragilaria spp.	Cyclo.-Stephano. gr. Nitzschia gr. Chlamy. gr.

Table [illegible] [illegible] Fort Devens in Remarks Area

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
January		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
February	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
March	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
April	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
May	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
June	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
July	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
August	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
September	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
October		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
November	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
December	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
January	[illegible]	[illegible]		[illegible]	[illegible]
February	[illegible]	[illegible]		[illegible]	[illegible]
March	[illegible]	[illegible]		[illegible]	[illegible]
April	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
May	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
June	[illegible]	[illegible]	[illegible]		
July	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
August	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
September	[illegible]	[illegible]		[illegible]	[illegible]
October	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
November	[illegible]	[illegible]		[illegible]	[illegible]
December	[illegible]	[illegible]		[illegible]	[illegible]

* [illegible] group
* [illegible]

[illegible]

See the following pages
for greater detail.

[illegible]

Table XIc Most Numerous Organisms at Each Station in Descending Order

	ABOVE GARRISON RESERVOIR	GARRISON RESERVOIR	BELOW GARRISON DAM	MANDAN, N. DAK. W.W. INTAKE	MOBRIDGE, S. DAK. W.W. INTAKE	MISSOURI RIVER AT PIERRE, S. DAK.	CHAMBERLAIN, S. DAK. W.W. INTAKE
January		Asterionella Euglena Heterotrichales sp.	Asterionella Euglena Heterotrichales sp.	Asterionella Heterotrichales sp. Dactylococcopsis	Asterionella Heterotrichales sp. Dactylococcopsis	Asterionella Heterotrichales sp. Anhistrodesmus & Chlamydomonas gr.	Asterionella Heterotrichales sp. Cyclo.-Steph. gr. & Chlamydomonas gr.
February	Cyclo.-Steph. gr.* Navicula gr.	Dactylococcopsis Asterionella Diatoma elongatum	Dactylococcopsis Asterionella Diatoma elongatum	Dactylococcopsis Diatoma elongatum Asterionella	Dactylococcopsis Asterionella Diatoma elongatum	Dactylococcopsis Asterionella Heterotrichales sp.	Heterotrichales sp. Dactylococcopsis Asterionella
March	Navicula gr. Chlamydomonas gr. Kitsenkia gr. & Rhizosolenia gr.	Cyclo. chaet.* Dactylococcopsis Asterionella & Diatoma elongatum	Cyclo. chaet. Asterionella Diatoma elongatum	Asterionella Dactylococcopsis Diatoma elongatum	Dactylococcopsis Asterionella Rhizosolenia gr.	Dactylococcopsis Asterionella Navicula gr.	Dactylococcopsis Asterionella Anhistrodesmus
April	Kitsenkia gr. Diatoma vulgare Cyclo.-Steph. gr.	Cyclo. chaet Asterionella Rhizosolenia gr.	Cyclo. chaet Asterionella Rhizosolenia gr.	Asterionella Dactylococcopsis Diatoma elongatum	Chlorella Asterionella Diatoma elongatum	Asterionella Chlamydomonas gr. Diatoma elongatum	Diatoma elongatum Asterionella Cyclo.-Steph. gr.
May	Asterionella Kitsenkia gr. Chlamydomonas gr.	Cyclo.-Steph. gr. Asterionella Chlamydomonas gr.	Cyclo.-Steph gr. Euglena Chlorella	Cyclo.-Steph. gr. Asterionella Diatoma elongatum	Cyclo.-Steph. gr. Asterionella Chlamydomonas gr.	Cyclo.-Steph. gr. Asterionella Chlamydomonas gr.	Cyclo.-Steph. gr. Asterionella Chlamydomonas gr.
June	Kitsenkia gr. Navicula gr. Surirella	Cyclo.-Steph. gr. Asterionella Trachelomonas	Cyclo.-Steph. gr. Euglena Navicula gr.	Rhizosolenia gr. Fragilaria spp. Cyclo.-Steph. gr.	Cyclo. chaet. Rhizosolenia gr. Cyclo.-Steph. gr.	Cyclo.-Steph. gr. Rhizosolenia gr. Asterionella	Cyclo.-Steph. gr. Rhizosolenia gr. Asterionella
July	Cyclo.-Steph. gr. Rhizosolenia gr. Scenedesmus bijuga	Chlamydomonas gr. Navicula gr. Trachelomonas	Navicula gr. Diatoma vulgare Coelastrum	Re[illegible]lo gr. Rh[illegible]osolenia gr. Ankrosderia	Rhizosolenia gr. Ankrosderia Navicula gr.	Cyclo.-Steph. gr. Rhizosolenia gr. Navicula gr.	Cyclo.-Steph. gr. Rhizosolenia gr. Navicula gr.
August	Navicula gr. Rhizosolenia gr. Kitsenkia gr.	Aphanizomenon Chlamydomonas gr. Cyclo.-Steph. gr.	Aphanizomenon Cyclo.-Steph. gr. Euglena	Navicula gr. Rhizosolenia gr. Cocillatoria gr.	Rhizosolenia gr. Navicula gr. Stichococcus	Cyclo.-Steph gr. Rhizosolenia gr. Cyclo. chaet.	Cyclo.-Steph. gr. Rhizosolenia gr. Navicula gr.
September	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.	Cyclo.-Steph. gr. Aphanizomenon	Cyclo.-Steph. gr. Aphanizomenon Euglena	Cyclo.-Steph. gr. Aphanizomenon Cocillatoria gr.	Cyclo.-Steph. gr. Aphanizomenon Navicula gr.	Cyclo.-Steph. gr. Rhizosolenia gr. Navicula gr.	Cyclo.-Steph. gr. Rhizosolenia gr. Navicula gr.
October		Cyclo.-Steph. gr. Aphanizomenon Euglena	Cyclo.-Steph. gr. Aphanizomenon Diatoma vulgare	Cyclo.-Steph. gr. Aphanizomenon Navicula gr.		Cyclo.-Steph. gr. Aphanizomenon Navicula gr.	Cyclo.-Steph. gr. Aphanizomenon Navicula gr.
November	Synedra gr. Navicula gr. Cyclo.-Steph. gr.	Cyclo.-Steph. gr. Euglena Asterionella	Cyclo.-Steph. gr. Euglena Gloeocystis	Cyclo.-Steph. gr. Navicula gr. Asterionella	Cyclo.-Steph. gr. Aphanizomenon Diatoma vulgare	Cyclo.-Steph. gr. Aphanizomenon Navicula gr., Kitsenkia gr., & Gloeocystis	Cyclo.-Steph. gr. Aphanizomenon Cyclo. chaet.
December	Cyclo.-Steph. gr. Euglena Dactylococcopsis & Cyclo. chaet.	Cyclo.-Steph. gr. Euglena Asterionella	Cyclo.-Steph. gr. Euglena Asterionella	Cyclo.-Steph. gr. Asterionella Navicula gr.	Cyclo.-Steph. gr. Asterionella Euglena	Cyclo.-Steph. gr. Gloeocystis Euglena	Cyclo.-Steph. gr. Asterionella Euglena

	FT. RANDALL RESERVOIR	BELOW FT. RANDALL DAM	NIOBRARA RIVER AT NIOBRARA, NEBR.	YANKTON, S. DAK. W.W. INTAKE	OMAHA, NEBR. W.W. INTAKE	COUNCIL BLUFFS, IA. W.W. INTAKE
January	Asterionella Chlamydomonas gr. Euglena	Asterionella Chlamydomonas gr. Euglena		Asterionella Anhistrodesmus Trachelomonas	Chlorella Chlamydomonas gr. Cyclo.-Steph. gr.	Chlamydomonas gr. Chlorella Gloeocystis
February	Asterionella Chlamydomonas gr. Euglena	Asterionella Euglena Chlamydomonas gr.		Asterionella Anhistrodesmus Chlamydomonas gr.	Asterionella Cyclo.-Steph. gr. Chlamydomonas gr.	Chlamydomonas gr. Asterionella Chlorella
March	Asterionella Anhistrodesmus Euglena	Asterionella Chlamydomonas gr. [illegible]		Asterionella Fragilaria spp. [illegible]	Asterionella Kitsenkia gr. [illegible]	Kitsenkia gr. [illegible]

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October		[illegible] Euglena	[illegible] Diatoma vulgare	[illegible] Navicula gr.		[illegible] Navicula gr.	[illegible] Navicula gr.
November	Synedra gr. Navicula gr. Cyclo.-Steph. gr.	Cyclo.-Steph. gr. Euglena Asterionella	Cyclo.-Steph. gr. Euglena Oscillatoria	Cyclo.-Steph. gr. Navicula gr. Asterionella	Cyclo.-Steph. gr. Aphanizomenon Diatoma vulgare	Cyclo.-Steph. gr. Aphanizomenon Navicula gr., Nitzschia gr., & Oscillatoria	Cyclo.-Steph. gr. Aphanizomenon Cyclo. chaet.
December	Cyclo.-Steph. gr. Euglena Dactylococcopsis & Cyclo. chaet.	Cyclo.-Steph. gr. Euglena Asterionella	Cyclo.-Steph. gr. Euglena Asterionella	Cyclo.-Steph. gr. Asterionella Navicula gr.	Cyclo.-Steph. gr. Asterionella Euglena	Cyclo.-Steph. gr. Oscillatoria Euglena	Cyclo.-Steph. gr. Asterionella Euglena

	FT. RANDALL RESERVOIR	BELOW FT. RANDALL DAM	NIOBRARA RIVER AT NIOBRARA, NEBR.	YANKTON, S. DAK. W.W. INTAKE	OMAHA, NEBR. W.W. INTAKE	COUNCIL BLUFFS, IA. W.W. INTAKE
January	Asterionella Chlamydomonas gr. Euglena	Asterionella Chlamydomonas gr. Euglena		Asterionella Ankistrodesmus Trachelomonas	Chlorella Chlamydomonas gr. Cyclo.-Steph. gr.	Chlamydomonas gr. Chlorella Oscillatoria
February	Asterionella Chlamydomonas gr. Euglena	Asterionella Euglena Chlamydomonas gr.		Asterionella Ankistrodesmus Chlamydomonas gr.	Asterionella Cyclo.-Steph. gr. Chlamydomonas gr.	Chlamydomonas gr. Asterionella Chlorella
March	Asterionella Ankistrodesmus Euglena	Asterionella Chlamydomonas gr. Euglena		Asterionella Fragilaria spp. Heterotrichales sp.	Asterionella Nitzschia gr. Synedra gr.	Nitzschia gr. Asterionella Synedra gr.
April	Cocconeis Euglena Heterotrichales sp.	Euglena Heterotrichales sp. Ankistrodesmus	Fragilaria spp. Navicula gr. Nitzschia gr.	Heterotrichales sp. Asterionella Lepthomonopsis	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.	Cyclo.-Steph. gr. Asterionella Cyclo.-Steph. gr.
May	Asterionella Cyclo.-Steph. gr. Ankistrodesmus	Asterionella Cyclo.-Steph. gr Diatoma elongatum	Ankistrodesmus Chlamydomonas gr. Rhizosolenia gr.	Asterionella Cyclo.-Steph. gr. Diatoma elongatum	Asterionella Rhizosolenia gr. Cyclo.-Steph. gr.	Asterionella Rhizosolenia gr. Diatoma elongatum & Cyclo.-Steph. gr.
June	Euglena Oscillatoria Asterionella	Euglena Cyclo.-Steph. gr. Asterionella	Scenes. dimorphus Ankistrodesmus Rhizosolenia gr.	Navicula gr. Cyclo.-Steph. gr. Rhizosolenia gr.		
July	Euglena Cyclo.-Steph. gr. Asterionella	Cyclo.-Steph. gr. Cocconeis Trachelomonas	Ankistrodesmus Rhizosolenia gr. Dictyosphaerium	Rhizosolenia gr. Navicula gr. Ankistrodesmus	Navicula gr. Rhizosolenia gr. Cyclo.-Steph. gr.	Navicula gr. Rhizosolenia gr. Cyclo.-Steph. gr.
August	Chlamydomonas gr. Cocconeis Cyclo.-Steph. gr.	Chlamydomonas gr. Cocconeis Cyclo.-Steph. gr.	Ankistrodesmus Rhizosolenia gr. Cymbella	Chlamydomonas gr. Cyclo.-Steph. gr. Ankistrodesmus	Cyclo.-Steph. gr. Rhizosolenia gr. Navicula gr.	Cyclo.-Steph. gr. Navicula gr. Dictyosphaerium
September	Cyclo.-Steph. gr. Chlamydomonas gr. Cocconeis	Cyclo.-Steph. gr. Chlamydomonas gr. Cocconeis		Cyclo.-Steph. gr. Chlamydomonas gr. Heterotrichales sp.	Cyclo.-Steph. gr. Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr. Navicula gr. Dictyosphaerium
October	Cyclo.-Steph. gr. Stichococcus Navicula gr.	Cyclo.-Steph. gr. Stichococcus Navicula gr.	Navicula gr. Fragilaria spp. Ankistrodesmus	Stichococcus Navicula gr. Cyclo.-Steph. gr.	Stichococcus Navicula gr. Cyclo.-Steph. gr.	Stichococcus Navicula gr. Cyclo.-Steph. gr.
November	Navicula gr. Stichococcus Cyclo.-Steph gr. & Euglena	Stichococcus Scenes. quadricauda Cyclo.-Steph. gr.		Navicula gr. Cyclo.-Steph. gr. Stichococcus	Navicula gr. Cyclo.-Steph. gr. Rhizosolenia gr.	Cyclo.-Steph. gr. Navicula gr. Rhizosolenia gr.
December	Euglena Cyclo.-Steph. gr. Chlamydomonas gr.	Cyclo.-Steph. gr. Euglena Chlamydomonas gr.		Navicula gr. Cyclo.-Steph. gr. Diatoma vulgare	Cyclo.-Steph. gr. Chlamydomonas gr. Rhizosolenia gr.	Cyclo.-Steph. gr. Euglena Rhizosolenia gr.

* Cyclotella-Stephanodiscus group
# Cyclotella chaetoceros

NOTE: In all cases when Average & Maximum counts for one month are the same, only one sample was collected for that month.

Table 23d
Most Numerous Organisms at Each Station in Descending Order

Month	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Mobridge	Pierre	Above Ft. Randall Reservoir	Ft. Randall Reservoir	Below Ft. Randall Dam	Niobrara	Gavins Point	Yankton	Omaha	Council Bluffs
1956 January	Navicula gr. Rhizosolenia gr. ◊ Asterionella Synedra gr. Trachelomonas	Asterionella Derepyxis Cyclo.-Steph. gr.*	Asterionella Derepyxis Cyclo.-Steph. gr.*	Asterionella Derepyxis Cyclo.-Steph. gr.*	Asterionella Cyclo.-Steph. gr.* Fragilaria crotonensis	Asterionella Cyclo.-Steph. gr.*% Derepyxis (All rest 2 occ. 1)	Asterionella Cyclo.-Steph. gr.* Derepyxis	Chlamydomonas gr. Cyclotella chaet.# Asterionella	Chlamydomonas gr. Cyclotella chaet.# Asterionella			Chlamydomonas gr. Asterionella Navicula gr.	Cyclo.-Steph. gr.* Chlamydomonas gr. Cyclotella chaet.#	Cyclo.-Steph. gr.* Chlamydomonas gr. Cyclotella chaet.#
February	Asterionella Navicula gr. Synedra gr.	Asterionella Chlamydomonas gr. Gloeocystis	Asterionella Derepyxis Cyclo.-Steph. gr.*% Chlamydomonas gr.	Asterionella Gomphonema Diatoma elongatum	Asterionella Cyclo.-Steph. gr.* (All rest are 1)	Asterionella Cyclo.-Steph. gr.* Derepyxis	Phacus Asterionella Euglena	Cyclotella chaet.# Asterionella Chlamydomonas gr.	Cyclotella chaet.# Asterionella Chlamydomonas gr.			Cyclotella chaet.# Chlamydomonas gr. Nitzschia gr.	Navicula gr. Chlamydomonas gr. Cyclotella chaet.#	Cyclo.-Steph. gr.* Chlamydomonas gr. Navicula gr.
March	Navicula gr. Synedra gr. Asterionella	Cyclotella chaet.# Chlamydomonas gr. Ankistrodesmus	Chlamydomonas gr. Asterionella Heterotrichales sp.	Cyclo.-Steph. gr.* Diatoma vulgare Diatoma elongatum	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Heterotrichales sp Asterionella	Cyclo.-Steph. gr.* Asterionella Ankistrodesmus	Cyclotella chaet.# Heterotrichales sp. Asterionella	Cyclotella chaet.# Heterotrichales sp. Asterionella			Cyclotella chaet.# Navicula gr. Asterionella	Navicula gr. Cyclotella chaet.# Heterotrichales sp.	Navicula gr. Cyclotella chaet.# Asterionella
April	Cyclo.-Steph. gr.* Chlamydomonas gr. Asterionella	Cyclotella chaet.# Chlamydomonas gr. Heterotrichales sp.	Cyclotella chaet.# Chlamydomonas gr. Heterotrichales sp.	Heterotrichales sp. Cyclotella chaet.# Chlamydomonas gr.	Cyclo.-Steph. gr.* Diatoma elongatum & Navicula gr. Rhizosolenia gr.		Heterotrichales sp. Cyclo.-Steph. gr.* Chlamydomonas gr.	Cyclotella chaet.# Asterionella Heterotrichales sp.	Cyclotella chaet.# Asterionella Heterotrichales sp.			Cyclotella chaet.# Asterionella Heterotrichales sp.	Heterotrichales sp. Asterionella Navicula gr.	Heterotrichales sp. Cyclotella chaet.# Asterionella
May		Cyclotella chaet.# Heterotrichales sp. Ankistrodesmus	Cyclotella chaet.# Heterotrichales sp. Asterionella	Cyclotella chaet.# Heterotrichales sp. Rhizosolenia gr.	Heterotrichales sp. Rhizosolenia gr. Dactylococcopsis & Ankistrodesmus	Heterotrichales sp. Cyclo.-Steph. gr.* Asterionella	Heterotrichales sp. Rhizosolenia gr. Cyclo.-Steph. gr.*	Cyclotella chaet.# Asterionella Ankistrodesmus	Cyclotella chaet.# Asterionella Euglena		Cyclotella chaet.# Asterionella Heterotrichales sp.	Asterionella Cyclotella chaet. Heterotrichales sp.	Asterionella Heterotrichales sp. Rhizosolenia gr.	Asterionella Heterotrichales sp. Navicula gr.
June	Navicula gr. Asterionella Cyclo.-Steph. gr.*	Ankistrodesmus Euglena Cyclo.-Steph. gr.*	Euglena Rhizosolenia gr. Diatoma elongatum	Rhizosolenia gr. Cyclo.-Steph. gr.* Pandorina	Cyclo.-Steph. gr.* Rhizosolenia gr. Navicula gr.	Cyclo.-Steph. gr.* Rhizosolenia gr. Navicula gr.	Cyclo.-Steph. gr.* Navicula gr. Heterotrichales sp.	Asterionella Derepyxis Euglena	Asterionella Derepyxis Cyclo.-Steph. gr.*		Ankistrodesmus Asterionella Cyclo.-Steph. gr.*	Asterionella Ankistrodesmus Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Asterionella Aphanizomenon	Cyclo.-Steph. gr.* Asterionella Aphanizomenon
July	Cyclo.-Steph. gr.* Rhizosolenia gr. Navicula gr.	Euglena Schroederia Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Euglena Asterionella	Navicula gr. Rhizosolenia gr. Cyclo.-Steph. gr.*	Rhizosolenia gr. Cyclo.-Steph. gr.* Navicula gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Euglena Gloeocystis Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Euglena Coccomonas & Gloeocystis		Cyclo.-Steph. gr.* Euglena Asterionella	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.
August	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Euglena Chlamydomonas gr. Cyclo.-Steph. gr.*	Aphanizomenon Cyclo.-Steph. gr.* Euglena	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Navicula gr. Rhizosolenia gr. Aphanizomenon	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Chlamydomonas gr. Coccomonas Euglena	Chlamydomonas gr. Coccomonas Euglena	Ankistrodesmus Scenedesmus quadricauda Fragilaria spp.	Cyclo.-Steph. gr.* Navicula gr. Dictyosphaerium	Cyclo.-Steph. gr.* Dictyosphaerium Navicula gr.	Cyclo.-Steph. gr.* Dictyosphaerium Navicula gr.	Cyclo.-Steph. gr. Navicula gr. Melosira (a)
September	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Aphanizomenon Navicula gr. & Euglena	Cyclo.-Steph. gr.* Aphanizomenon Euglena	Cyclo.-Steph. gr.* Aphanizomenon gr. Navicula gr.	Aphanizomenon Rhizosolenia gr. Navicula gr.	Navicula gr. Cyclo.-Steph. gr.* Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Chlamydomonas gr. Coccomonas Oocystis	Chlamydomonas gr. Oocystis Cyclo.-Steph. gr.*	Dictyosphaerium Chlamydomonas gr. Cyclotella chaet.#	Chlamydomonas gr. Sphaerocystis Euglena	Chlamydomonas gr. Sphaerocystis & Dictyosphaerium Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Coccomonas Dictyosphaerium	Cyclo.-Steph. gr.* Dictyosphaerium Navicula gr.
October	Rhizosolenia gr. Navicula gr. Cyclotella chaet.#	Navicula gr. Cyclo.-Steph. gr.* Nitzschia gr.	Cyclo.-Steph. gr.* Euglena Aphanizomenon	Cyclo.-Steph. gr.* Navicula gr. Aphanizomenon	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Euglena Cyclo.-Steph. gr.*% Stichococcus Oocystis	Euglena Cyclo.-Steph. gr.* Stichococcus	Navicula gr. Rhizosolenia gr. Chlamydomonas	Stichococcus Chlamydomonas gr. Euglena	Cyclo.-Steph. gr.* Euglena Oocystis	Cyclo.-Steph. gr.* Stichococcus Navicula gr.	Stichococcus Cyclo.-Steph. gr.* Navicula gr. & Scenedesmus bijuga
November	Navicula gr. Synedra gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Euglena	Cyclo.-Steph. gr.* Euglena Aphanizomenon	Cyclo.-Steph. gr.* Navicula gr. Aphanizomenon	Cyclo.-Steph. gr.* Gloeocystis Aphanizomenon	Cyclo.-Steph. gr.* Navicula gr. Synedra gr.	Cyclo.-Steph. gr.* Navicula gr. Aphanizomenon	Euglena Stichococcus Scenedesmus quadricauda	Euglena Stichococcus Scenedesmus quadricauda	Navicula gr. Fragilaria spp. Diatoma vulgare & Synedra gr.		Stichococcus Chlamydomonas gr. Trachelomonas	Cyclo.-Steph. gr.* Stichococcus Navicula gr. & Crucigenia quadrata	Cyclo.-Steph. gr.* Stichococcus Cyclotella (a)
December	Navicula gr. Cyclotella chaet.# Euglena	Euglena Cyclo.-Steph. gr.*% Asterionella	Cyclo.-Steph. gr.* Asterionella Euglena	Cyclo.-Steph. gr.* Asterionella Euglena	Euglena Cyclo.-Steph. gr.* Navicula gr.		Cyclo.-Steph. gr.* Navicula gr. Euglena	Euglena Stichococcus Chlamydomonas gr.	Euglena Stichococcus Chlamydomonas gr.			Euglena Chlamydomonas gr. Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Euglena Cyclotella chaet.#	Cyclo.-Steph. gr.* Chlorella Chlamydomonas gr.
1957 January	Navicula gr. Chlamydomonas Rhizosolenia	Asterionella Cyclotella (a) Chlamydomonas	Asterionella Cyclotella (a) Heterotrichales sp.	Asterionella Cyclo.-Steph. gr. Chlamydomonas	Asterionella Cyclo.-Steph. gr. Chlamydomonas		Asterionella Navicula gr. Chlamydomonas Euglena	Euglena Chlamydomonas Gymnodinium	Chlamydomonas Euglena Cyclo.-Steph.			Chlamydomonas Euglena Gomphonema	Cyclotella (a) Chlamydomonas Cyclo.-Steph.	Cyclotella (a) Cyclo.-Steph. Chlamydomonas
February	Navicula gr. Synedra gr. Rhizosolenia	Asterionella Cyclotella (a) Euglena	Asterionella Cyclotella (a) Rhizosolenia	Asterionella Heterotrichales sp. Aphanizomenon	Asterionella Cyclotella (a) Heterotrichales sp.		Asterionella Navicula gr. Heterotrichales sp.	Chlamydomonas Euglena Cyclotella (a)	Chlamydomonas Cyclotella (a) Euglena Cyclo.-Steph.			Cyclotella (a) Chlamydomonas Cyclo.-Steph.	Chlamydomonas Cyclotella (a) Cyclo.-Steph.	Chlamydomonas Cyclotella (a) Cyclo.-Steph.
March	Navicula gr. Synedra gr. Surirella	Asterionella Chlamydomonas Euglena	Asterionella Chlamydomonas Cyclotella (a)	Asterionella Navicula gr. Rhizosolenia	Asterionella Heterotrichales sp. Chlamydomonas	Asterionella Navicula gr. Aphanizomenon	Asterionella Navicula gr. Cyclo.-Steph.	Cyclotella (a) Asterionella Euglena	Cyclotella (a) Asterionella Gymnodinium			Cyclotella (a) Asterionella Chlamydomonas	Cyclotella (a) Cyclo.-Steph. Asterionella	Cyclotella (a) Cyclo.-Steph. Asterionella
April	Navicula gr. Surirella Asterionella	Chlamydomonas Coccomonas Cyclotella (a)	Chlamydomonas Coccomonas Cyclotella (a)	Cyclotella (a) Diatoma vulgare Navicula gr.	Cyclotella (a) Rhizosolenia Navicula gr.	Asterionella Navicula gr. Cyclo.-Steph.	Chlamydomonas Asterionella Navicula gr.	Cyclotella (a) Asterionella Staurpym	Cyclotella (a) Asterionella Coccomonas			Cyclotella (a) Asterionella Diatoma elongata	Cyclotella (a) Asterionella Diatoma elongata	Cyclotella (a) Navicula gr. Asterionella
May	Surirella Navicula gr. Diatoma vulgare	Coccomonas Cyclotella (a) Diatoma elongata	Coccomonas Cyclotella (a) Chlamydomonas	Cyclotella (a) Coccomonas Navicula gr.	Cyclotella (a) Coccomonas Navicula gr.	Navicula gr. Asterionella Rhizosolenia	Navicula gr. Chlamydomonas Rhizosolenia	Asterionella Heterotrichales sp. Cyclotella (a)	Asterionella Heterotrichales sp. Cyclo.-Steph.			Asterionella Cyclotella (a) Cyclo.-Steph.	Asterionella Cyclo.-Steph. Navicula	Asterionella Cyclo.-Steph. Navicula
June	Oocystis Navicula Oscillatoria	Euglena Asterionella Navicula gr.	Coccomonas Euglena Navicula gr.	Rhizosolenia Navicula gr. Cyclotella (a)	Navicula gr. Rhizosolenia Cyclo.-Steph.	Cyclo.-Steph. Fragilaria crotonensis Aphanizomenon	Cyclo.-Steph. Heterotrichales sp. Rhizosolenia	Gloeocystis Asterionella Oocystis	Asterionella Euglena Gloeocystis			Cyclo.-Steph. Euglena Asterionella	Cyclo.-Steph. Asterionella Synedra	Cyclo.-Steph. Asterionella Diatoma elongata

*Cyclotella-Stephanodiscus group
#Cyclotella chaetoceras

aphanizomenon group
[illegible]

XXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXX

A

Table 22d
Most Numerous Organisms at Each Station
in Descending Order

Month	Above Garrison Reservoir	Garrison Reservoir	Below Garrison Dam	Mandan	Mobridge	Pierre	Above Ft. Randall Reservoir	Ft. Randall Reservoir
1956								
January	Navicula gr. Rhizosolenia gr. & Asterionella Synedra gr. Trachelomonas	Asterionella Derepyxis Cyclo.-Steph. gr.*	Asterionella Derepyxis Cyclo.-Steph. gr.*	Asterionella Derepyxis Cyclo.-Steph. gr.*	Asterionella Cyclo.-Steph. gr.* Fragilaria crotonensis	Asterionella Cyclo.-Steph. gr.*& Derepyxis (All rest 2 exc. 1)	Asterionella Cyclo.-Steph. gr.* Derepyxis	Chlamydomonas gr. Cyclotella chaet.θ Asterionella
February	Asterionella Navicula gr. Synedra gr.	Asterionella Chlamydomonas gr. Gloeocystis	Asterionella Derepyxis Cyclo.-Steph. gr.*& Chlamydomonas gr.	Asterionella Gomphonema Diatoma elongatum	Asterionella Cyclo.-Steph. gr.* (All rest are 1)	Asterionella Cyclo.-Steph. gr.* Derepyxis	Phacus Asterionella Euglena	Cyclotella chaet.θ Asterionella Chlamydomonas gr.
March	Navicula gr. Synedra gr. Asterionella	Cyclotella chaet.θ Chlamydomonas gr. Ankistrodesmus	Chlamydomonas gr. Asterionella Heterotrichales sp.	Cyclo.-Steph. gr.* Diatoma vulgare Diatoma elongatum	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Heterotrichales sp Asterionella	Cyclo.-Steph. gr.* Asterionella Ankistrodesmus	Cyclotella chaet.θ Heterotrichales sp. Asterionella
April	Cyclo.-Steph. gr.* Chlamydomonas gr. Asterionella	Cyclotella chaet.θ Chlamydomonas gr. Heterotrichales sp.	Cyclotella chaet.θ Chlamydomonas gr. Heterotrichales sp.	Heterotrichales sp. Cyclotella chaet.θ Chlamydomonas gr.	Cyclo.-Steph. gr.* Diatoma elongatum & Navicula gr. Rhizosolenia gr.		Heterotrichales sp. Cyclo.-Steph. gr.* Chlamydomonas gr.	Cyclotella chaet.θ Asterionella Heterotrichales sp.
May		Cyclotella chaet.θ Heterotrichales sp. Ankistrodesmus	Cyclotella chaet.θ Heterotrichales sp. Asterionella	Cyclotella chaet.θ Heterotrichales sp. Rhizosolenia gr.	Heterotrichales sp. Rhizosolenia gr. Dactylococcopsis & Ankistrodesmus	Heterotrichales sp. Cyclo.-Steph. gr.* Asterionella	Heterotrichales sp. Rhizosolenia gr. Cyclo.-Steph. gr.*	Cyclotella chaet.θ Asterionella Ankistrodesmus
June	Navicula gr. Asterionella Cyclo.-Steph. gr.*	Ankistrodesmus Euglena Cyclo.-Steph. gr.*	Euglena Rhizosolenia gr. Diatoma elongatum	Rhizosolenia gr. Cyclo.-Steph. gr.* Pandorina	Cyclo.-Steph. gr.* Rhizosolenia gr. Navicula gr.	Cyclo.-Steph. gr.* Rhizosolenia gr. Navicula gr.	Cyclo.-Steph. gr.* Navicula gr. Heterotrichales sp.	Asterionella Derepyxis Euglena
July	Cyclo.-Steph. gr.* Rhizosolenia gr. Navicula gr.	Euglena Schroederia Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Euglena Asterionella	Navicula gr. Rhizosolenia gr. Cyclo.-Steph. gr.*	Rhizosolenia gr. Cyclo.-Steph. gr.* Navicula gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Euglena Gloeocystis Cyclo.-Steph. gr.*
August	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Euglena Chlamydomonas gr. Cyclo.-Steph. gr.*	Aphanizomenon Cyclo.-Steph. gr.* Euglena	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Navicula gr. Rhizosolenia gr. Aphanizomenon	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Chlamydomonas gr. Coccomonas Euglena
September	Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Aphanizomenon Navicula gr. & Euglena	Cyclo.-Steph. gr.* Aphanizomenon Euglena	Cyclo.-Steph. gr.* Aphanizomenon gr. Navicula gr.	Aphanizomenon Rhizosolenia gr. Navicula gr.	Navicula gr. Cyclo.-Steph. gr.* Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Chlamydomonas gr. Coccomonas Oocystis
October	Rhizosolenia gr. Navicula gr. Cyclotella chaet.θ	Navicula gr. Cyclo.-Steph. gr.* Nitzschia gr.	Cyclo.-Steph. gr.* Euglena Aphanizomenon	Cyclo.-Steph. gr.* Navicula gr. Aphanizomenon	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Euglena Cyclo.-Steph. gr.*& Stichococcus Oocystis
November	Navicula gr. Synedra gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Euglena	Cyclo.-Steph. gr.* Euglena Aphanizomenon	Cyclo.-Steph. gr.* Navicula gr. Aphanizomenon	Cyclo.-Steph. gr.* Gloeocystis Aphanizomenon	Cyclo.-Steph. gr.* Navicula gr. Synedra gr.	Cyclo.-Steph. gr.* Navicula gr. Aphanizomenon	Euglena Stichococcus Scenedesmus quadricauda
December	Navicula gr. Cyclotella chaet.θ Euglena	Euglena Cyclo.-Steph. gr.*& Asterionella	Cyclo.-Steph. gr.* Asterionella Euglena	Cyclo.-Steph. gr.* Asterionella Euglena	Euglena Cyclo.-Steph. gr.* Navicula gr.		Cyclo.-Steph. gr.* Navicula gr. Euglena	Euglena Stichococcus Chlamydomonas gr.
1957								
January	Navicula gr. Chlamydomonas Rhizosolenia	Asterionella Cyclotella (a) Chlamydomonas	Asterionella Cyclotella (a) Heterotrichales sp.	Asterionella Cyclo.-Steph. gr. Chlamydomonas	Asterionella Cyclo.-Steph. gr. Chlamydomonas		Asterionella Navicula gr. Chlamydomonas Euglena	Euglena Chlamydomonas Gymnodinium
February	Navicula gr. Synedra gr. Rhizosolenia	Asterionella Cyclotella (a) Euglena	Asterionella Cyclotella (a) Rhizosolenia	Asterionella Heterotrichales sp. Aphanizomenon	Asterionella Cyclotella (a) Heterotrichales sp.		Asterionella Navicula gr. Heterotrichales sp.	Chlamydomonas Euglena Cyclotella (a)
March	Navicula gr. Synedra gr. Surirella	Asterionella Chlamydomonas Euglena	Asterionella Chlamydomonas Cyclotella (a)	Asterionella Navicula gr. Rhizosolenia	Asterionella Heterotrichales sp. Chlamydomonas	Asterionella Navicula gr. Aphanizomenon	Asterionella Navicula gr. Cyclo.-Steph.	Cyclotella (a) Asterionella Euglena
April	Navicula gr. Surirella Asterionella	Chlamydomonas Coccomonas Cyclotella (a)	Chlamydomonas Coccomonas Cyclotella (a)	Cyclotella (a) Diatoma vulgare Navicula gr.	Cyclotella (a) Rhizosolenia Navicula gr.	Asterionella Navicula gr. Cyclo.-Steph.	Chlamydomonas Asterionella Navicula gr.	Cyclotella (a) Asterionella Dinobryon
May	Surirella Navicula gr. Diatoma vulgare	Coccomonas Cyclotella (a) Diatoma elongata	Coccomonas Cyclotella (a) Chlamydomonas	Cyclotella (a) Coccomonas Navicula gr.	Cyclotella (a) Coccomonas Navicula gr.	Navicula gr. Asterionella Rhizosolenia	Navicula gr. Chlamydomonas Rhizosolenia	Asterionella Heterotrichales sp. Cyclotella (a)
June	Oocystis Navicula Oscillatoria	Euglena Asterionella Navicula gr.	Coccomonas Euglena Navicula gr.	Rhizosolenia Navicula gr. Cyclotella (a)	Navicula gr. Rhizosolenia Cyclo.-Steph.	Cyclo.-Steph. Fragilaria crotonensis Aphanizomenon	Cyclo.-Steph. Heterotrichales sp. Rhizosolenia	Gloeocystis Asterionella Oocystis

*Cyclotella-Stephanodiscus group
θCyclotella chaetoceras

ephanodiscus group
aetoceras

B

Table 23d
Most Numerous Organisms at Each Station
in Descending Order

Pierre	Above Pt. Randall Reservoir	Pt. Randall Reservoir	Below Pt. Randall Dam	Niobrara	Gavins Point	Yankton	Omaha	Council Bluffs
Asterionella Cyclo.-Steph. gr.*& Dorepy- & (All rest 2 exc. 1)	Asterionella Cyclo.-Steph. gr.* Dorepyxis	Chlamydomonas gr. Cyclotella chaet.Ø Asterionella	Chlamydomonas gr. Cyclotella chaet.Ø Asterionella			Chlamydomonas gr. Asterionella Navicula gr.	Cyclo.-Steph. gr.* Chlamydomonas gr. Cyclotella chaet.Ø	Cyclo.-Steph. gr.* Chlamydomonas gr. Cyclotella chaet.Ø
Asterionella Cyclo.-Steph. gr.* Dorepyxis	Fharus Asterionella Euglena	Cyclotella chaet.Ø Asterionella Chlamydomonas gr.	Cyclotella chaet.Ø Asterionella Chlamydomonas gr.			Cyclotella chaet.Ø Chlamydomonas gr. Nitzschia gr.	Navicula gr. Chlamydomonas gr. Cyclotella chaet.Ø	Cyclo.-Steph. gr.* Chlamydomonas gr. Navicula gr.
Cyclo.-Steph. gr.* Heterotrichales sp Asterionella	Cyclo.-Steph. gr.* Asterionella Ankistrodesmus	Cyclotella chaet.Ø Heterotrichales sp. Asterionella	Cyclotella chaet.Ø Heterotrichales sp. Asterionella			Cyclotella chaet.Ø Navicula gr. Asterionella	Navicula gr. Cyclotella chaet.Ø Heterotrichales sp.	Navicula gr. Cyclotella chaet.Ø Asterionella
	Heterotrichales sp. Cyclo.-Steph. gr.* Chlamydomonas gr.	Cyclotella chaet.Ø Asterionella Heterotrichales sp.	Cyclotella chaet.Ø Asterionella Heterotrichales sp.			Cyclotella chaet.Ø Asterionella Heterotrichales sp.	Heterotrichales sp. Asterionella Navicula gr.	Heterotrichales sp. Cyclotella chaet.Ø Asterionella
Heterotrichales sp. Cyclo.-Steph. gr.* Asterionella	Heterotrichales sp. Rhizosolenia gr. Cyclo.-Steph. gr.*	Cyclotella chaet.Ø Asterionella Ankistrodesmus	Cyclotella chaet.Ø Asterionella Euglena		Cyclotella chaet.Ø Asterionella Heterotrichales sp.	Asterionella Cyclotella chaet. Heterotrichales sp.	Asterionella Heterotrichales sp. Rhizosolenia gr.	Asterionella Heterotrichales sp. Navicula gr.
Cyclo.-Steph. gr.* Rhizosolenia gr. Navicula gr.	Cyclo.-Steph. gr.* Navicula gr. Heterotrichales sp.	Asterionella Dorepyxis Euglena	Asterionella Dorepyxis Cyclo.-Steph. gr.*		Ankistrodesmus Asterionella Cyclo.-Steph. gr.*	Asterionella Ankistrodesmus Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Asterionella Aphanizomenon	Cyclo.-Steph. gr.* Asterionella Aphanizomenon
Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Euglena Gloeocystis Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Euglena Coccomonas & Gloeocystis		Cyclo.-Steph. gr.* Euglena Asterionella	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.
Rhizosolenia gr. Navicula gr. Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Navicula gr. Rhizosolenia gr.	Chlamydomonas gr. Coccomonas Euglena	Chlamydomonas gr. Coccomonas Euglena	Ankistrodesmus Scenedesmus quadri- cauda Fragilaria spp.	Cyclo.-Steph. gr.* Navicula gr. Dictyosphaerium	Cyclo.-Steph. gr.* Dictyosphaerium Navicula gr.	Cyclo.-Steph. gr.* Dictyosphaerium Navicula gr.	Cyclo.-Steph. gr. Navicula gr. Melosira (a)
Navicula gr. Cyclo.-Steph. gr.* Rhizosolenia gr.	Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Chlamydomonas gr. Coccomonas Oocystis	Chlamydomonas gr. Oocystis Cyclo.-Steph. gr.*	Dictyosphaerium Chlamydomonas gr. Cyclotella chaet.Ø	Chlamydomonas gr. Sphaerocystis Euglena	Chlamydomonas gr. Sphaerocystis & Dictyosphaerium Cyclo.-Steph. gr.*	Cyclo.-Steph. gr.* Coccomonas Dictyosphaerium	Cyclo.-Steph. gr.* Dictyosphaerium Navicula gr.
Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Cyclo.-Steph. gr.* Navicula gr. Stichococcus	Euglena Cyclo.-Steph. gr.*& Stichococcus Oocystis	Euglena Cyclo.-Steph. gr.* Stichococcus	Navicula gr. Rhizosolenia gr. Chlamydomonas	Stichococcus Chlamydomonas gr. Euglena	Cyclo.-Steph. gr.* Euglena Oocystis	Cyclo.-Steph. gr.* Stichococcus Navicula gr.	Stichococcus Cyclo.-Steph. gr.* Navicula gr. & Scenedesmus bijuga
Cyclo.-Steph. gr.* Navicula gr. Synedra gr.	Cyclo.-Steph. gr.* Navicula gr. Aphanizomenon	Euglena Stichococcus Scenedesmus quadri- cauda	Euglena Stichococcus Scenedesmus quadri- cauda	Navicula gr. Fragilaria spp. Diatoma vulgare & Synedra gr.		Stichococcus Chlamydomonas gr. Trachelomonas	Cyclo.-Steph. gr.* Stichococcus Navicula gr. & Crucigenia quadrata	Cyclo.-Steph. gr.* Stichococcus Cyclotella (a)
	Cyclo.-Steph. gr.* Navicula gr. Euglena	Euglena Stichococcus Chlamydomonas gr.	Euglena Stichococcus Chlamydomonas gr.			Euglena Chlamydomonas gr. Cyclo. -Steph. gr.*	Cyclo.-Steph. gr.* Euglena Cyclotella chaet.Ø	Cyclo.-Steph. gr.* Chlorella Chlamydomonas gr.
	Asterionella Navicula gr. Chlamydomonas Euglena Asterionella Navicula gr. Heterotrichales sp.	Euglena Chlamydomonas Gymnodinium Chlamydomonas Euglena Cyclotella (a)	Chlamydomonas Euglena Cyclo.-Steph. Chlamydomonas Cyclotella (a) Euglena Cyclo.-Steph.			Chlamydomonas Euglena Chlamydomonas Cyclotella (a) Chlamydomonas Cyclo.-Steph.	Cyclotella (a) Chlamydomonas Cyclo.-Steph. Chlamydomonas Cyclotella (a) Cyclo.-Steph.	Cyclotella (a) Cyclo.-Steph. Chlamydomonas Chlamydomonas Cyclotella (a) Cyclo.-Steph.
Asterionella Navicula gr. Aphanizomenon	Asterionella Navicula gr. Cyclo.-Steph.	Cyclotella (a) Asterionella Euglena	Cyclotella (a) Asterionella Gymnodinium			Cyclotella (a) Asterionella Chlamydomonas	Cyclotella (a) Cyclo.-Steph. Asterionella	Cyclotella (a) Cyclo.-Steph. Asterionella
Asterionella Navicula gr. Cyclo.-Steph.	Chlamydomonas Asterionella Navicula gr.	Cyclotella (a) Asterionella Dinobryon	Cyclotella (a) Asterionella Coccomonas			Cyclotella (a) Asterionella Diatoma elongata	Cyclotella (a) Asterionella Diatoma elongata	Cyclotella (a) Navicula gr. Asterionella
Navicula gr. Asterionella Rhizosolenia	Navicula gr. Chlamydomonas Rhizosolenia	Asterionella Heterotrichales sp. Cyclotella (a)	Asterionella Heterotrichales sp. Cyclo.-Steph.			Asterionella Cyclotella (a) Cyclo.-Steph.	Asterionella Cyclo.-Steph. Navicula	Asterionella Cyclo.-Steph. Navicula
Cyclo.-Steph. Fragilaria crotonensis Aphanizomenon	Cyclo.-Steph. Heterotrichales sp. Rhizosolenia	Gloeocystis Asterionella Oocystis	Asterionella Euglena Gloeocystis			Cyclo.-Steph. Euglena Asterionella	Cyclo.-Steph. Asterionella Synedra	Cyclo.-Steph. Asterionella Diatoma elongata
		ephemdiscus group asteceras						

Table 20

Summary of Individual Miscellaneous Water Analyses (ppm)

Above Garrison Reservoir

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
9-10-52	48	20.4		0.4					
10-9-52	54.5	22.3		0.4					
12-1-52	48.4	25.4		0.5					
2-2-53	48.4	22.4		0.5					

Bismarck, North Dakota

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
9-10-52	48	22.3		0.6					
10-17-52	54.5	23.2		0.6					
11-14-52	58.5	25.8		0.5	36.8		173.5		
12-19-52	69.5	30.1		0.5	80.0		248.0		
1-9-53	63.6								
2-19-53	63.2	26.7			6.0		124.0		
4-8-53	48.0	21.4		0.5					
5-12-53	47.6	23.6		0.6	37.5		104.2		
7-20-53	33.6	13.6		0.5	3.5		26.0		
8-26-53	53.6	19.4		0.6					

Pierre, South Dakota

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-25-52	44	18	8	0.7					
9-22-52	46	23	14	0.6					
10-28-52	53	27	10						
11-21-52	60	21	8	0.8					
12-22-52	83	27	12	0.8					
1-21-53	80	44	12	0.5					
2-23-53	72	37	12	0.5					
3-20-53	74	39	12	0.4					
4-20-53	69	34	10	0.5					
5-20-53	60	36	10	0.4					
6-19-53	42	28	12	0.3					

Above Pt. Randall Reservoir

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-18-52	44	17	11						
8-28-52	46	18	16	0.7	53	3.8	181	0.05	0.00
9-15-52	50	20	15	0.7	54	4.3	184	0.03	0.00
9-29-52	51	22	10						
10-8-52	53	23	11						
10-14-52	49	21	9						
10-30-52	56	21	11	0.6	54	4.1	189	0.03	0.00
11-3-52	51	23	13						
11-19-52	61	28	12						
11-24-52	59	23	10	0.7	67	5.2	191	0.00	0.00
12-3-52	75	27	11						
12-16-52	71	27	12	0.7	81	5.8	245	0.00	0.00
1-19-53	61	49	10	0.6	54.6	3.4	243	0.05	0.05
1-28-53	66	36	12						
2-2-53	75	44	10						
2-9-53	62	44	15						
2-16-53	68	44	12						
2-23-53	71	37	10	0.5	56.3	3.8	225	0.05	0.05
3-2-53	68	40	12						
3-9-53	72	37	10						
3-16-53	70	29	15						
3-23-53	75	29	12	0.5	58.1	3.8	234	0.05	0.05
4-2-53	59	37	10						
4-11-53	59	27	10						
4-21-53	61	30	10	0.4	57.2	4.3	244	0.05	0.05
4-27-53	64	37	12						
5-8-53	76	34	10						
5-11-53	58	32	10						
5-18-53	61	25	20	0.5	45	3.3	233	0.05	0.05
6-3-53	56	44	12						
6-4-53	55	33	25						
6-15-53	64	30	25	0.4	64	6.0	215	0.05	0.05
6-22-53	54	23	15						
6-29-53	53	25	15						

Below Fort Randall Reservoir

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-19-52	43	17	10						
8-27-52	46	18	10	0.6					
9-4-52	50	19	13						
9-10-52	49	18	12						
9-17-52	51	23	12						
9-23-52	47	22	10	0.6					
10-1-52	51	24	14						
10-8-52	54	22	10						
10-15-52	48	22	11						
10-21-52	47	21	8	0.6					
10-29-52	55	24	10						
11-5-52	50	22	11						
11-12-52	55	21	9						
11-18-52	60	30	9						
11-26-52	68	31	9	0.8					
12-5-52	75	35	10						
12-11-52	79	33	13						
12-18-52	78	37	11						
12-24-52	82	36	11	0.8					
12-30-52	83	39	11						
1-5-53	77	42	12						

Below Fort Randall Reservoir (Cont'd)

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
1-14-53	66	32	10						
1-21-53	75	44	12	0.4					
1-27-53	67	45	15						
2-4-53	66	41	12						
2-12-53	72	37	12						
2-18-53	68	34	10						
2-25-53	60	46	12	0.4					
3-4-53	70	33	12						
3-10-53	70	43	10						
3-18-53	63	24	12						
3-25-53	75	29	10	0.5					
4-1-53	56	24	10						
4-8-53	66	27	18						
4-15-53	70	28	10						
4-22-53	62	34	10	0.4					
4-28-53	69	44	10						
5-8-53	70	23	10						
5-13-53	59	27	20						
5-20-53	82	20	12						
5-27-53	65	27	18	0.3					
6-3-53	62	41	12						
6-10-53	57	29	15						
6-16-53	64	28	20						
6-24-53	52	31	12	0.3					

See the following pages for greater detail.

Yankton, South Dakota

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-20-52	63	16	12						
8-27-52	36	17	47	0.7	52	4.1	179	0.05	0.00
9-3-52	49	17	8						
9-10-52	41	18	22						
9-17-52	38	27	31						
9-24-52	51	19	14	0.6	52	3.9	178	0.03	0.00
10-1-52	51	22	13						
10-8-52	53	22	12						
10-15-52	51	23	13						
10-21-52	53	23	13	0.7	53	4.3	179	0.03	0.00
10-29-52	62	25	14						
11-5-52	51	24	12						
11-12-52	54	20	11						
11-18-52	59	21	13						
11-26-52	62	19	12	0.7	56	4.9	193	0.00	0.00
12-3-52	72	26	14						
12-10-52	63	25	18						
12-16-52	64	22	17						
12-26-52	71	26	21	0.6	67	6.0	224	0.00	0.00
12-31-52	84	31	14						
1-7-53	81	35	25						
1-14-53	58	42	18						
1-22-53	58	54	15	0.5	59.8	5.1	242	0.05	0.05
1-27-53	54	46	25						
2-4-53	63	43	25						
2-11-53	72	37	17						
2-18-53	51	42	20						
2-25-53	61	45	15	0.5	56.4	3.8	233	0.05	0.05
3-4-53	62	34	15						
3-10-53	70	33	15						
3-18-53	63	19	12						
3-25-53	70	29	12	0.4	53.9	4.6	234	0.05	0.05
4-1-53	44	28	10						
4-9-53	61	30	15						
4-15-53	63	33	12						
4-22-53	64	28	10	0.3	56.4	4.2	221	0.05	0.05
4-29-53	69	34	10						
5-6-53	76	36	10						
5-13-53	63	36	15						
5-20-53	68	25	10						
5-27-53	65	32	20	0.5	60.9	4.8	241	0.05	0.05
6-3-53	63	43	25						
6-10-53	68	33	10						
6-17-53	64	36	15	0.5	66	6.3	224	0.05	0.05
6-24-53	67	28	12						

Omaha, Nebraska

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-21-52	68	17	11	0.6					
9-8-52	67	23	14						
9-25-52	56	22	12	0.5					
10-16-52	56	23	12	0.6					
10-28-52	56	23	12						
11-13-52	66	21	11						
11-29-52	68	22	10	0.8					
12-8-52	79	24	12						
12-22-52	81	29	17	0.7					
12-31-52	85	30	17						
1-16-53	66	47	25	0.6					
2-2-53	72	47	28						
2-6-53	79	37	12						
2-23-53	76	39	22	0.6					
3-12-53	77	33	22						
3-26-53	74	31	10	0.5					
4-10-53	68	30	12						
4-23-53	75	34	13	0.5					
5-11-53	76	31	12						
5-30-53	76	36	13	0.6					
6-13-53	57	32	12	0.5					

Table 20

Summary of Individual Miscellaneous Water Analyses (ppm)

Above Garrison Reservoir

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
9-10-52	48	20.4		0.6					
10-9-52	54.5	22.3		0.6					
12-1-52	68.6	25.4		0.5					
2-2-53	68.6	22.4		0.5					

Bismarck, North Dakota

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
9-10-52	48	22.3		0.6					
10-17-52	54.5	23.2		0.6					
11-14-52	58.5	25.8		0.5	56.8		173.5		
12-19-52	69.5	30.1		0.5	80.0		248.0		
1-9-53	63.6								
2-19-53	63.2	26.7			6.0		124.0		
4-8-53	48.0	21.4		0.5					
5-12-53	47.6	23.6		0.6	37.5		104.2		
7-20-53	33.6	13.6		0.5	3.5		26.0		
8-26-53	53.6	19.4		0.6					

Pierre, South Dakota

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-25-52	44	18	8	0.7					
9-22-52	46	23	14	0.6					
10-20-52	53	27	10						
11-21-52	60	21	8	0.8					
12-22-52	83	27	12	0.8					
1-21-53	80	44	12	0.5					
2-23-53	72	37	12	0.5					
3-20-53	76	39	12	0.4					
4-20-53	69	34	10	0.5					
5-20-53	60	36	10	0.4					
6-19-53	42	28	12	0.3					

Above Ft. Randall Reservoir

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-18-52	44	17	11						
8-28-52	46	18	16	0.7	53	3.8	181	0.05	0.00
9-15-52	50	20	15	0.7	54	4.3	184	0.03	0.00
9-29-52	51	22	10						
10-8-52	53	23	11						
10-14-52	49	21	9						
10-20-52	56	21	11	0.6	54	4.1	189	0.03	0.00
11-3-52	51	23	13						
11-19-52	61	22	12						
11-26-52	59	23	10	0.7	67	5.2	191	0.00	0.00
12-5-52	75	27	11						
12-16-52	71	27	12	0.7	81	5.8	265	0.00	0.00
1-19-53	61	49	10	0.6	54.6	3.4	243	0.05	0.05
1-28-53	66	36	12						
2-2-53	75	44	10						
2-9-53	62	44	15						
2-16-53	68	44	12						
2-23-53	71	37	10	0.5	56.5	3.8	225	0.05	0.05
3-2-53	68	40	12						
3-9-53	72	37	10						
3-16-53	70	29	15						
3-23-53	75	29	12	0.5	58.1	3.8	254	0.05	0.05
[illegible]	[illegible]	[illegible]	[illegible]						

Below Fort Randall Reservoir (Cont'd)

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
1-14-53	66	32	10						
1-21-53	75	44	12	0.4					
1-27-53	67	45	15						
2-4-53	66	41	12						
2-12-53	72	37	12						
2-18-53	68	34	10						
2-25-53	60	46	12	0.4					
3-4-53	70	33	12						
3-10-53	70	43	10						
3-18-53	63	24	12						
3-25-53	75	29	10	0.5					
4-1-53	56	24	10						
4-8-53	66	27	18						
4-15-53	70	28	10						
4-22-53	62	34	10	0.4					
4-28-53	69	44	10						
5-8-53	70	23	10						
5-13-53	59	27	20						
5-20-53	82	20	12						
5-27-53	65	27	18	0.3					
6-3-53	62	41	12						
6-10-53	57	29	15						
6-16-53	64	28	20						
6-24-53	52	21	12	0.3					

Yankton, South Dakota

Date	Ca	Mg	SiO_2	F	Na	K	SO_4	Cu	Zn
8-20-52	43	16	12						
8-27-52	34	17	47	0.7	52	4.1	179	0.05	0.00
9-3-52	49	17	8						
9-10-52	41	18	22						
9-17-52	38	27	31						
9-24-52	51	19	14	0.6	52	3.9	178	0.03	0.00
10-1-52	51	22	13						
10-8-52	53	22	12						
10-15-52	51	23	13						
10-21-52	53	23	13	0.7	53	4.3	179	0.03	0.00
10-29-52	42	25	14						
11-5-52	51	24	12						
11-12-52	54	20	11						
11-18-52	59	21	13						
11-26-52	62	19	12	0.7	56	4.9	193	0.00	0.00
12-3-52	72	26	14						
12-10-52	63	25	18						
12-16-52	64	22	17						
12-26-52	71	26	21	0.6	67	6.0	224	0.00	0.00
12-31-52	84	31	14						
1-7-53	81	35	35						
1-14-53	58	42	18						
1-22-53	58	56	15	0.5	59.8	3.1	242	0.05	0.05
1-27-53	54	40	25						
2-4-53	63	43	35						
2-11-53	72	37	17						
2-18-53	51	42	20						
2-25-53	61	45	23	0.5	56.4	3.8	222	0.05	0.05
3-4-53	62	34	15						
3-10-53	70	33	15						
3-18-53	63	19	12						
3-25-53	70	29	12	0.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2-13-53	72	37	12	0.3					
3-20-53	76	39	12	0.4					
4-20-53	69	34	10	0.5					
5-20-53	60	36	10	0.4					
6-19-53	42	28	12	0.3					

Above Ft. Randall Reservoir

8-18-52	44	17	11						
8-28-52	46	18	16	0.7	53	3.8	181	0.05	0.00
9-15-52	50	20	15	0.7	54	4.3	184	0.03	0.00
9-29-52	51	22	10						
10-8-52	53	23	11						
10-14-52	49	21	9						
10-20-52	56	21	11	0.6	54	4.1	189	0.03	0.00
11-3-52	51	23	13						
11-19-52	61	22	12						
11-26-52	59	23	10	0.7	67	5.2	191	0.00	0.00
12-5-52	75	27	11						
12-16-52	71	27	12	0.7	81	5.8	265	0.00	0.00
1-19-53	61	49	10	0.6	54.6	3.4	243	0.05	0.05
1-28-53	66	36	12						
2-2-53	75	44	10						
2-9-53	62	44	15						
2-16-53	68	44	12						
2-23-53	71	37	10	0.5	56.5	3.8	215	0.05	0.05
3-2-53	68	40	12						
3-9-53	72	37	10						
3-16-53	70	29	15						
3-23-53	75	29	12	0.5	58.1	3.8	254	0.05	0.05
4-2-53	59	27	10						
4-11-53	59	27	10						
4-21-53	61	30	10	0.4	37.2	4.3	244	0.05	0.05
4-27-53	64	37	12						
5-8-53	76	34	10						
5-11-53	58	32	10						
5-18-53	61	25	28	0.5	65	3.5	233	0.05	0.05
6-3-53	56	44	12						
6-9-53	55	33	25						
6-15-53	66	30	25	0.4	64	6.0	215	0.05	0.05
6-22-53	56	23	15						
6-29-53	53	25	15						

Below Fort Randall Reservoir

8-19-52	45	17	10	
8-27-52	46	18	10	0.6
9-4-52	50	19	13	
9-10-52	49	18	12	
9-17-52	51	23	12	
9-23-52	47	22	10	0.6
10-1-52	51	24	14	
10-8-52	56	22	10	
10-15-52	48	22	11	
10-21-52	47	21	8	0.6
10-29-52	55	24	10	
11-5-52	50	22	11	
11-12-52	55	21	9	
11-18-52	60	20	9	
11-26-52	68	21	9	0.8
12-5-52	75	25	10	
12-11-52	79	22	13	
12-16-52	78	27	11	
12-24-52	82	26	11	0.8
12-30-52	83	29	11	
1-5-53	77	42	12	

8-20-52	43	16	12						
8-27-52	34	17	47	0.7	52	4.1	179	0.05	0.00
9-3-52	49	17	8						
9-10-52	41	18	22						
9-17-52	38	27	31						
9-24-52	51	19	14	0.6	52	3.9	178	0.03	0.00
10-1-52	51	22	13						
10-8-52	53	22	12						
10-15-52	51	23	13						
10-21-52	53	23	13	0.7	53	4.3	179	0.03	0.00
10-29-52	42	25	14						
11-5-52	54	24	12						
11-12-52	54	20	11						
11-18-52	59	21	13						
11-26-52	62	19	12	0.7	56	4.9	193	0.00	0.00
12-3-52	72	26	14						
12-10-52	63	25	18						
12-16-52	64	22	17						
12-26-52	71	26	21	0.6	67	6.0	224	0.00	0.00
12-31-52	84	31	14						
1-7-53	81	35	35						
1-14-53	58	42	18						
1-22-53	56	56	15	0.5	59.8	3.1	242	0.05	0.05
1-27-53	54	40	25						
2-4-53	63	43	35						
2-11-53	72	37	17						
2-18-53	51	42	20						
2-25-53	61	45	23	0.5	56.4	3.8	222	0.05	0.05
3-4-53	62	34	15						
3-10-53	70	33	15						
3-18-53	63	19	12						
3-25-53	70	29	12	0.4	53.9	4.6	254	0.05	0.05
4-1-53	44	28	10						
4-9-53	61	20	15						
4-15-53	63	33	12						
4-22-53	64	28	10	0.3	56.4	4.2	221	0.05	0.05
4-29-53	69	34	10						
5-6-53	76	34	10						
5-13-53	63	24	15						
5-20-53	68	25	10						
5-27-53	65	32	20	0.5	60.9	4.8	241	0.05	0.05
6-3-53	63	43	25						
6-10-53	68	33	10						
6-17-53	64	36	15	0.5	66	6.3	224	0.05	0.05
6-24-53	47	28	12						

Omaha, Nebraska

8-21-52	48	17	11	0.6
9-9-52	47	23	14	
9-25-52	54	22	12	0.5
10-16-52	56	23	12	0.6
10-29-52	56	23	12	
11-13-52	64	21	11	
11-29-52	68	22	10	0.8
12-8-52	79	24	12	
12-22-52	81	29	17	0.7
12-31-52	85	30	17	
1-16-53	64	47	35	0.6
2-2-53	72	47	28	
2-6-53	79	37	12	
2-23-53	76	39	22	0.6
3-12-53	77	33	32	
3-26-53	74	31	10	0.3
4-10-53	68	30	12	
4-23-53	75	34	15	0.5
5-11-53	74	31	12	
5-30-53	74	26	12	0.4
6-13-53	57	32	12	0.3

most numerous groups each month was present at all stations. Frequently the same three groups were most abundant at each locality, although not always in the same order; and in some instances a single group dominated at all stations sampled. Seasonal qualitative similarity at various stations was evident before and after impoundment at Ft. Randall Reservoir, at stations in affected and unaffected reaches of the river.

In 1954, each reservoir assumed considerable domination of plankton composition in the river below it. Garrison and Ft. Randall Reservoirs exhibited little similarity. The Garrison Reservoir plankton population largely dominated the river all the way down to the headwaters of Ft. Randall Reservoir; and Ft. Randall Reservoir plankton types were generally predominant in the river as far as Omaha.

Groups attaining numerical superiority in 1952 - 1953 usually composed the most numerous classes in 1954. However, Melosira granulata angustissima, failing to develop more than a fraction of its 1953 population, never became the predominant form at any station; Asterionella enjoyed dominance over longer periods of time; and rank in most numerous classes was at times attained by groups that were much less numerous or absent in 1952 - 1953. Diatoma elongatum attained the number one level during one month at all stations below Ft. Randall, but never reached any position of prominence in or below Garrison Reservoir. Asterionella became most abundant in Ft. Randall in late winter and early spring, whereas its greatest development in Garrison came in late fall and early winter. In most respects qualitative differences between the two reservoirs involved abundance at different seasons of the generally predominant Missouri River groups and not greatly varying annual populations. Specific differences may be noted by reference to Table 22.

During most seasons, numerical preponderance was held by one of the diatom groups. Green algae, Chlamydomonas gr., Gloeocystis, Stichococcus, etc., were most numerous upon few occasions, usually during periods of low total plankton density in cold water seasons. Blue-green algae (Aphanizomenon) ranked with predominant groups in summer in North Dakota reaches, and upon one occasion were most numerous at Mandan. The reservoirs were largely instrumental in determination of plankton groups in the river below each, but they showed no seasonal agreement in populations. The Garrison type population survived down into the headwaters of Ft. Randall Reservoir, and it is possible that greater similarity may characterize the two reservoir discharges in the future.

Displaced benthic forms did not attain the prominence they displayed in previous years.

In 1955, diatoms remained the predominant general group at most stations during most seasons; but blue-green algae, green algae, euglenophytes, and heterotrich yellow-green algae replaced them as monthly dominant groups at a number of stations.

It is evident from entries in Table 22 that season and location both played definite roles in selection of the most numerous group. In January, 1955, Asterionella held dominance over the entire river and reservoir system from Garrison to Yankton. In February it was replaced by the blue-green alga Dactylococcopsis in Garrison Reservoir and downstream to Pierre, and by a small member of the Heterotrichales at Chamberlain, but still maintained dominance in Ft. Randall, extending downriver to Omaha. In March, Asterionella was still dominant in Ft. Randall and below; Dactylococcopsis had been replaced by Cyclotella chaetoceras in Garrison Reservoir, but was still dominant at

Mobridge and Pierre, and had replaced the small Heterotrichales as the most numerous organism at Chamberlain. At Mandan, however, Asterionella had regained dominance. In April, a month of increasing plankton density in and below Garrison Reservoir, the small Cyclotella was still its dominant form, but Asterionella had decreased significantly in Ft. Randall. River stations exhibited considerable variation in April, dominance being held by Asterionella at Mandan and Pierre, by Chlorella at Mobridge (between Mandan and Pierre), at Chamberlain by Diatoma elongatum, by Heterotrichales at Yankton, and by the Rhizosolenia group at Omaha and Council Bluffs. In May the Cyclotella-Stephanodiscus group gained superiority in Garrison and extended its dominance over the river down to Ft. Randall Reservoir, in and below which Asterionella had again developed into the most numerous organism. In June, a month of general decline in plankton density, the Cyclotella-Stephanodiscus group still reigned in Garrison Reservoir and at most stations downstream to Ft. Randall Reservoir, where Euglena was most numerous. July was characterized by considerable variation between stations, even between reservoirs and their discharges. In August the blue-green Aphanizomenon gained dominance in Garrison Reservoir, but was not represented in the three most numerous groups at other stations. Cyclotella-Stephanodiscus plankters still held on at Pierre, Chamberlain, Omaha, and Council Bluffs, while Chlamydomonas was most numerous in Ft. Randall and at Yankton. In September the Cyclotella-Stephanodiscus group gained numerical superiority at all stations beginning with Garrison Reservoir. Aphanizomenon appeared below Garrison during this month. The Cyclotella-Stephanodiscus group maintained its general dominance in October, losing out to Stichococcus, a green alga, at Yankton, Omaha, and Council Bluffs. In November and December, Cyclotella-Stephanodiscus organisms prevailed or figured No. 2 in density at all locations.

Increase to a dominant position was limited to relatively few of the rather long list of phytoplankters. Diatoms attained that role more frequently than representatives of other algal groups, and were usually dominant when plankton densities reached their highest levels. Other algal groups whose representatives at times exhibited numerical superiority were: Green Algae--Volvacales (Chlamydomonas and Coccomonas), Chlorococcales (Chlorella), Ulotrichales (Stichococcus); Yellow-Green Algae--Xanthophyceae (Heterotrichales); Euglenophyta --Euglenophyceae (Euglena); Blue-Green Algae--Chroococcales (Dactylococcopsis) and Hormogonales (Aphanizomenon).

Reservoir influences upon qualitative aspects of plankton varied. In some instances it appeared that organisms gained a start in a reservoir and then spread downstream, assuming dominance at all points. The early Asterionella bloom spread from Garrison Reservoir in October 1954 to Chamberlain in November and December, through Ft. Randall Reservoir in January, 1955, and on to Omaha in February. It maintained its dominance in Ft. Randall in February and March, but lost out to other groups in Garrison after January. This downstream progression of an algal bloom from one reservoir through another in winter may result from north to south temperature decline. Asterionella exhibited dense development in Garrison in December when water temperature was 0° C., and attained its dominance in Ft. Randall in January and February when temperature was at or near 0° C. However, Asterionella attained greater density in Ft. Randall in May when water temperature was about 12° C. Thus, if Asterionella development is assumed due to a downstream temperature decline during winter, it will be necessary to assume also that different strains of the species were involved in the winter and summer blooms. In the river between the two reservoirs, the appearance of Asterionella is readily explained by the fact that the major part

of discharge originated in Garrison releases. Its occurrence in Ft. Randall, however, may hardly be assumed due to replacement of impounded water, as water entering the reservoir amounted to only about 12 per cent of that left in storage in January. Experimentation will be necessary to establish the details of Garrison Reservoir influence, and whether or not the growth in the lower reservoir was the result of temperature decline.

Water containing a dense growth of a certain phytoplankter may only seed areas into which it flows, but it may also introduce elements that stimulate growth of that particular group or species. For instance, Asterionella did not get started in Ft. Randall until three months after it had been carried to that locality in Garrison releases. Similarly, it required over a month to develop to a dominant position at Omaha, although constantly introduced in Ft. Randall releases going by that point. It may be argued that conditions eventually changed sufficiently to permit its greater development at Omaha, but what factor would have more influence than continued entrance of water in which the organism had been growing? In May, the Asterionella bloom immediately extended to Omaha; but the organism had ranged within the three dominant positions at Yankton and Council Bluffs in April.

The above account is not intended to belittle the role of local factors in inducing variation at individual stations, as it must be assumed that delays in initiating local populations of forms contributed from upstream are caused by local influences. Local factors were evident in dominance alteration, but individual station variation would have been less striking in some instances if samples had consisted of cross-sectional composites. The factor responsible for chemical differences at Omaha and Council Bluffs was also involved in plankton variation between the two stations. Blooms that

appeared simultaneously at all stations, e.g., Cyclotella-Stephanodiscus in September, may be considered the result of general climatological and river conditions.

Inflow into Garrison Reservoir had little influence upon the composition of its plankton and during several months Ft. Randall Reservoir resisted influences of upstream water and developed its own characteristic plankton population. However, reservoir algal populations were generally much more alike than in 1954, and Garrison conditions exerted some influence in Ft. Randall. Inflow of the Niobrara River, which developed dense plankton growths in late spring and summer, was sometimes instrumental in inducing qualitative changes at Yankton. Gavins Point Reservoir exerted no apparent influence upon plankton composition of its inflow.

Similar plankton populations appeared at times in Ft. Randall and Garrison Reservoirs in 1956, but they were not duplicated in the river between. On those occasions it would appear that general environmental conditions as influenced by season offset the normal reservoir tendency toward individuality. In March, April, and May, Cyclotella chaetoceras was the most numerous organism in each of the two reservoirs, but it did not attain a dominant position at any intervening river station below Mandan. Heaviest 1956 plankton densities occurred in the reservoirs during this three-month period, and their concentrations were not closely approached at river stations. Independent growths of Cyclotella chaetoceras were responsible for this numerical superiority. Euglena attained dominance in both reservoirs during July and December. It was also the most numerous group in Garrison in August and in Ft. Randall in November. Some other similarities are evident in Table 22.

Garrison Reservoir phytoplankton composition was quite like that of the river above it in February, April, and December. With the exception of April, these were months of low plankton density. Downstream extent of the Garrison Reservoir type of population varied during the year. It did not reach Mandan during February, March, April, June, July, and August. Reservoir releases differed from the reservoir in position of dominant groups upon occasion as indicated in Table 22. These discrepancies reflect variations between reservoir surface and depths--a condition usually most pronounced when densities were low.

Organisms attaining dominance at Mandan maintained this position down to Mobridge only during the months of January, February, March, October, and November. Groups dominant at Mobridge were also most numerous at Chamberlain in January, May, June, October, and November. The predominant groups at Chamberlain were never duplicated in Ft. Randall Reservoir the same month or during succeeding months. Populations developed in Ft. Randall apparently were influential in Gavins Point Reservoir during January-April and September, but during the months of record Niobrara River populations had no effects upon dominant Gavins Point plankton composition. Yankton, only three miles below Gavins Point Dam, differed from the reservoir in May, June, and October. The Yankton type populations endured to Omaha only in May, July, and August. Council Bluffs differed from Omaha in manners indicated in Table 22.

In the first half of 1957, Garrison and Ft. Randall Reservoirs did not develop similar plankton populations at any time. In general, Garrison Reservoir dominants extended downstream to Chamberlain during January-April, but were replaced in June in reservoir discharges, and in May and June at all stations from Mandan to Chamberlain (Table 22). The most numerous organism in Ft. Randall releases was also the predominant form at Yankton except in June. Discharged

water did not always repeat conditions found near the reservoir surface. Omaha differed from Yankton in January and February, but thereafter assumed a general similarity. Council Bluffs exhibited only minor variations from the Omaha pattern. The Garrison population was quite dissimilar to that in the river upstream.

Conditions that led to general reservoir growth of a particular organism in 1956 were obviously not repeated in 1957. During both years the tendency toward station individuality was well expressed, yet reservoirs had far-reaching influences over downstream river reaches. Ft. Randall Reservoir often determined plankton composition in Gavins Point, but was not significantly affected by growths developed in Garrison. Influences of this nature are undoubtedly modified by intervening distance and relative or absolute size of the downstream impoundment.

Quantitative Features

In 1952 and 1953, the greatest concentration of organisms observed in the main stem was slightly more than 3,000 organisms per ml. Over extended periods, particularly during ice cover and high discharge seasons, plankton density was quite low-frequently less than 20 per ml. Available records (8, 9, and 10) indicate that numbers were generally much higher in the majority of tributaries--a difference also indicative of plankton attrition in the main stem.

Seasonal Variation:

Variation in phytoplankton volume (N units per ml.) in 1952 and 1953 and 1954 is shown in Figures 3 and 4. Volumetric units are used here to avoid redrawing of figures. N units may be converted to ppm by volume by multiplying

by 0.011175.

Ignoring effects of Ft. Randall Reservoir, it may be noted that greatest plankton densities occurred during the low flow period that endured almost a month between the 1953 May and June rises. Plankton increase to a lesser extent characterized lowered discharges following the general period of high stages in March and early April. Densities were relatively high during the August to November periods when the river received highest releases from Ft. Peck and exhibited rather uniform discharges. Lowest 1952 - 1953 concentrations were associated with ice cover and high discharges.

Relationships of plankton density to discharge do not necessarily indicate a simple dilution-concentration process. Considering physical features alone, the period from August to November 1953, by virtue of its uniformity of discharge and relatively low turbidity, was seemingly more suited to plankton growth than times intermediate to high spring and summer discharges. Increased concentration of nutrient elements in streams following periods of increased runoff has been noted (4, 5, and 6) and it appears likely that greater algal production following high stages was associated with chemical as well as physical improvement of their environment. Algal increases at those times cannot be referred to tributary inflow as they characterized all stations and were due to one or two predominant groups (Table 23).

Ft. Randall Reservoir discharged an almost constant supply of clear water after recession of the 1953 June rise. The maximum observed plankton concentrations developed below the reservoir about one and one-half months later. A progressive downstream increase was evident all the way to Yankton--the lowermost station sampled during July, August, and September, 1953 (Table 23, Figures 3 and 4). A few organisms introduced by the Niobrara River were

Table 23.
Average and Maximum Phytoplankton Densities
No. per ml.

See the following pages for greater detail.

Stations	Above Garrison Reservoir Av.	Max.	Garrison Reservoir Av.	Max.	Below Garrison Dam Av.	Max.	Hensler Av.	Max.	Bismarck Av.	Max.	Mobridge Av.	Max.	Pierre Av.	Max.	Above Ft. Randall Reservoir Av.	Max.	Ft. Randall Reservoir Av.	Max.	Below Ft. Randall Dam Av.	Max.	Yankton Av.	Max.	Omaha Av.	Max.	Council Bluffs Av.	Max.
1952																												
August									95	95*			53	53*	69	108			55	70	75	77	16	16*		
September	66	66*											28	28*	46	56			78	112	342	875	112	123		
October	40	40*							37	37*			33	33*	32	39			56	79	78	103	57	89		
November									48	48*			29	29*	47	50			38	51	63	73	51	57		
December									198	198*			23	23*	26	39			13	30	23	32	235	267		
1953																												
January													15	15*	23	27			26	29	30	35	21	21*		
February	11	11*							11	11*			16	16*	18	26			19	30	25	42	17	27		
March									9	9*			22	22*	18	30			9	14	27	63	72	120		
April													117	117*	48	130			76	178	86	192	91	139		
May	191	191*							100	100*			390	390*	152	320			157	378	387	996	809	1410		
June													* **	* **	206	565			129	280	723	2386	68	68*		
July									10	10*			27	27*	230	239*	610	610*	213	403	626	626*				
August									10	10*					94	94*	268	349	285	524	785	1335				
September															41	41*	365	728	425	1059	1566	3123				
October													12	13	18	18*	88	167	46	66	103	206	127	168		
November													12	12*	22	32	23	43	26	41	46	95	98	145		
December													3	3*	20	36	35	51	31	37	19	28	64	159		
Annual													65	390	76	565	198[1]	728[1]	120	1059	369	3123	152	1410		
1954																												
January													25	25*	8	10	101	178	209	326	48	96	139	213		
February													17	25	3	5	306	448	144	246	63	93	110	136		
March													10	10*	6	8	266	342	331	494	188	289	110	171		
April													12	20	1	1*	472	391	322	399	604	789	453	580		
May													52	85	459	827	1781	6562	1559	4965	1534	4803	784	1847		
June													187	379	54	118	1029	3159	1206	3442	618	1279	385	1076		
July			35	35*	51	51*	38	38*					638	822	209	374	12	21	13	23	77	118	159	192		
August	24	24*	92	198	73	128	59	85			116	116*	103	133	111	285	331	921	299	862	791	1826	681	1216		
September	82	108	95	290	143	292	171	325			173	191	156	265	298	678	167	388	190	342	557	963	294	542	39	39*
October	68	68*	165	268	159	222	98	249			65	65*	165	232	164	287	42	76	65	55	123	188	22	31	39	41
November	99	114	232	373	187	223	190	230			209	259	334	334*	391	806	105	197	200	285	178	222	24	51	82	136
December	98	98*	437	674	377	604	385	560			183	183*	251	297	611	738	232	279	216	252	99	156	68	73	61	106
Annual			192[1]	674	180[1]	604	176[1]	560			181	359	144	822	185	827	403	6562	630	4965	426	4803	264	1847		
1955																												
January			425	868	450	795	250	408			192	192*	206	215	276	302	225	253	230	290	106	132	326	462	268	375
February	12	12*	206	239	196	263	159	222			227	227*	240	287	345	411	323	357	274	312	150	192	120	154	92	106
March	12	12*	415	853	387	670	200	253			160	160*	119	197	198	300	436	555	322	447	123	182	68	70	36	52
April	33	33*	711	1397	982	1787	412	578			1592	1592*	252	390	830	1103	238	444	321	628	161	345	90	197	60	118
May	107	131	264	529	307	710	506	607			129	200	233	386	69	100	1116	1522	840	1114	1067	1986	270	270	325	325
June	34	40	23	70	46	130	57	85			686	1263	132	154	402	1172	104	196	82	108	201	312				
July	59	106	31	72	38	91	44	94			213	298	332	364	179	418	46	70	22	35	297	376	220	306	363	563
August	70	124	20	58	15	23	50	67			218	266	454	811	344	963	401	965	349	906	550	791	371	578	363	578
September	135	135*	69	85	58	88	118	222			146	146*	142	142*	106	172	390	614	415	724	343	1088	306	475	370	509
October			173	247	192	286	224	299					393	467	366	473	269	495	274	566	255	340	263	348	232	327
November	104	149	106	146	110	146	92	132			257	257*	243	243*	137	376	59	171	44	73	39	61	62	78	84	92
December	25	30	48	69	44	48	32	36			23	23*	28	34	21	26	82	144	67	91	33	45	686	1642	368	534
Annual	62	149	207	1397	233	1787	175	407			339	1592	248	811	295	1172	320	1522	277	1114	304	1986	259	1642	228	578
1956																												
January	10	11	124	161	56	63	58	67				32*	39	43	31	45	127	215	79	110	39	56	83	113	52	67
February	27	29	47	72	36	54	26	33				16*	30	40	57	130	225	330	118	150	38	54	33	56	22	39
March	30	47	27	66	18	38	40	73				12*	72	104	26	49	3534	10449	4739	9979	1139	1709	52	101	42	107
April	278	488	3628	6972	2529	6086	105	261				62*			66	162	6487	9759	6012	6860	1395	4013	66	118	139	200
May	0	0*	1067	3029	1334	2671	138	181			159	170	102	129	167	338	614	1023	554	1168	558	826	219	425	239	343
June	26	32	49	76	57	75	74	118			88	119	149	179	382	463	120	191	130	263	478	782	534	928	616	1239
July	300	382	19	55	13	38	53	71			90	93	74	102	153	225	42	66	34	63	348	604	422	618	313	654
August	357	615	12	29	20	39	43	62			60	82	98	122	101	202	227	628	207	559	314	430	476	536	338	761
September	448	874	15	24	22	28	53	68			78	94	135	182	170	196	52	76	66	100	414	659	281	363	233	326
October	670	965	450	1349	62	81	92	129			161	209	392	481	546	1190	116	301	125	187	115	143	118	142	87	104
November	138	186	82	94	59	76	53	66			43	48	61	73	65	95	153	256	140	232	87	112	126	168	210	476
December	62	66	51	65	35	56	20	58			15	15			33	68	99	108	86	95	63	107	197	344	255	361
Annual	216	965	509	6972	377	6086	63	261			76	209	115	481	148	1190	1190	10449	1066	9979	420	4013	202	928	210	1239
1957																												
January	44	50	271	662	50	81	81	96			27	39			34	44	111	131	88	123	27	57	4.	1014	374	1037
February	19	19*	388	615	76	136	99	115			110	115			139	175	66	112	45	74	169	477	264	720	343	884
March	63	72	272	355	101	124	100	130			94	103	75	78	141	206	512	837	392	754	4574	10554	14445	32467	14127	31041
April	170	215	186	251	148	207	140	223			150	270	56	99	108	196	579	865	594	772	12079	25617	16889	40918	16363	39907
May	62	105	261	425	253	417	167	354			303	470	157	157*	271	351	211	358	199	275	591	666	582	736	594	696
June	22	22*	58	84	53	85	138	254			332	387	17	17	758	1525	58	93	56	112	420	423	680	744	439	687
Semi-Annual	74	215	237	662	115	417	120	354			168	470			208	1525	269	865	244	772	3102	25617	6785	40918	6208	39907

*Only one record
**Less than 4 per ml.
[1] Semi-annual

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Table 23.
Average and Maximum Phytoplankton Densities
No. per ml.

Stations	Above Garrison Reservoir		Garrison Reservoir		Below Garrison Dam		Mandan		Bismarck		Mobridge		Pierre		Above Ft. Randall Reservoir		Ft. Randall Reservoir		Below Ft. Randall Dam		Yankto
	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.
1952																					
August									95	95*			53	53*	69	108			55	70	75
September	66	66*											28	28*	46	56			78	112	342
October	40	40*							37	37*			33	33*	32	39			54	79	78
November									48	48*			29	29*	47	58			38	51	63
December									298	298*			23	23*	26	39			13	30	23
1953																					
January													15	15*	23	27			26	29	30
February	11	11*							11	11*			14	14*	18	26			19	30	25
March									9	9*			22	22*	18	30			9	14	27
April													117	117*	48	130			76	178	86
May	191	191*							100	100*			390	390*	152	320			157	378	387
June													* **	* **	206	565			129	280	723
July									10	10*			27	27*	239	239*	410	410*	213	403	626
August									10	10*					94	94*	268	549	285	524	785
September															41	41*	365	728	425	1059	1566
October													12	13	18	18*	86	167	46	66	103
November													12	12*	22	32	23	45	26	41	46
December													5	5*	20	36	35	51	31	37	19
Annual													65	390	76	565	198[1]	728[1]	120	1059	369
1954																					
January													25	25*	8	10	101	178	209	324	48
February													17	25	3	5	306	448	144	246	63
March													10	10*	6	8	266	342	331	494	188
April													12	20	1	1*	472	591	522	599	604
May													52	85	459	827	1781	4562	1559	4965	1534
June													187	379	54	118	1029	3159	1284	3442	618
July			35	35*	51	51*	38	38*					438	822	209	374	12	21	13	23	77
August	24	24*	92	198	73	128	59	85			116	116*	103	133	111	285	331	921	299	862	791
September	82	108	95	290	143	292	171	325			173	191	154	245	298	478	167	386	190	342	557
October	68	68*	145	268	159	222	98	249			45	45*	165	232	164	287	42	76	45	55	123
November	99	114	232	373	187	223	190	230			289	359	334	334*	591	806	105	197	200	285	178
December	98	98*	437	674	377	604	385	560			183	183*	251	297	411	738	232	279	214	252	99
Annual			192[1]	674	180[1]	604	174[1]	560			181	359	144	822	185	827	403	4562	430	4965	426
1955																					
January			425	868	450	795	250	408			192	192*	206	215	276	302	225	253	230	290	106
February	12	12*	206	239	196	243	159	222			227	227*	240	287	345	411	323	357	274	312	150
March	12	12*	415	853	387	670	200	253			160	160*	119	197	198	300	436	555	322	447	123
April	33	33*	711	1397	982	1787	412	578			1592	1592*	252	390	850	1103	258	444	321	428	161
May	107	131	264	529	307	710	506	607			129	200	233	386	69	100	1116	1522	840	1114	1067
June	34	40	23	70	46	130	57	85			686	1263	132	154	402	1172	104	196	82	108	201
July	59	106	31	72	38	91	44	94			213	298	332	364	179	418	46	70	22	35	297
August	70	124	20	58	15	23	50	67			218	266	454	811	544	943	401	965	349	906	550
September	135	135*	69	85	58	88	118	222			146	146*	142	142*	106	172	390	614	415	724	543
October			173	247	192	286	224	299					393	447	364	473	269	495	274	566	255
November	104	149	106	146	110	146	92	132			257	257*	243	243*	137	376	59	171	44	73	39
December	25	30	48	49	44	48	32	36			23	23*	28	34	21	26	82	144	67	91	32
Annual	62	149	207	1397	233	1787	175	607			339	1592	242	811	295	1172	320	1522	277	1114	304
1956																					
January	10	11	124	161	56	63	58	67				32*	39	43	31	45	127	215	79	110	39
February	27	29	47	72	36	54	26	33				14*	30	40	57	130	225	330	118	150	38
March	30	47	27	66	18	38	40	73				12*	72	104	26	49	5534	10449	4739	9979	1139
April	278	488	3628	6972	2529	6086	105	261				42*			66	162	6487	9759	6012	8860	1395
May	0	0*	1067	2029	1334	2671	138	181			159	170	102	129	167	338	614	1023	554	1168	558
June	26	32	49	76	57	75	74	118			88	119	149	179	382	465	120	191	130	263	478
July	300	382	19	55	13	38	53	71			90	93	74	102	153	225	42	66	34	63	348
August	357	615	12	29	20	39	42	62			60	82	98	122	101	202	227	628	207	559	314
September	448	874	15	24	22	28	53	68			76	94	135	162	170	196	52	76	66	100	414
October	670	965	450	1349	62	81	92	129			141	209	392	481	546	1190	116	201	125	187	115
November	138	186	82	94	59	76	53	66			43	48	61	73	65	95	153	256	140	232	87
December	62	68	51	65	35	56	20	58			15	15			33	48	99	108	86	95	63
Annual	216	965	509	6972	377	6086	63	261			76	209	115	481	148	1190	1190	10449	1066	9979	420
1957																					
January	44	50	271	662	50	81	61	96			27	39			34	44	111	131	88	123	27
February	19	19*	388	615	76	136	98	115			110	115			139	175	66	112	45	74	169
March	63	72	272	355	101	124	100	130			94	103	75	78	141	206	512	837	392	754	4574
April	178	215	186	251	148	207	140	223			150	270	56	99	108	196	579	865	594	772	12079
May	62	105	261	425	253	417	167	354			303	470	157	157*	271	551	211	358	199	275	591
June	22	22*	58	84	53	85	158	254			332	387	17	17	758	1525	58	93	56	112	420
Semi-Annual	74	215	237	662	115	417	120	354			168	470			208	1525	269	865	244	772	3102

*Only one record
**Less than 4 per ml.
[1]Semi-annual

Table 23.
Average and Maximum Phytoplankton Densities
No. per ml.

Below Garrison Dam		Mandan		Bismarck		Mobridge		Pierre		Above Ft. Randall Reservoir		Ft. Randall Reservoir		Below Ft. Randall Dam		Yankton		Omaha		Council Bluffs	
Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.
				95	95*			53	53*	69	108			55	70	75	77	16	16*		
								28	28*	46	56			78	112	342	875	112	123		
				37	37*			33	33*	32	39			54	79	78	103	57	89		
				48	48*			29	29*	47	58			38	51	63	73	51	57		
				298	298*			23	23*	26	39			13	30	23	32	235	267		
								15	15*	23	27			26	29	30	35	21	21*		
				11	11*			14	14*	18	26			19	30	25	42	17	27		
				9	9*			22	22*	18	30			9	14	27	43	72	120		
								117	117*	48	130			76	178	86	192	51	139		
				100	100*			390	390*	152	320			157	378	387	996	809	1410		
								* **	* **	206	565			129	280	723	2386	68	68*		
				10	10*			27	27*	239	239*	410	410*	213	403	626	626*				
				10	10*					94	94*	268	549	285	524	785	1335				
										41	41*	365	728	425	1059	1566	3123				
								12	13	18	18*	86	167	46	66	103	206	127	168		
								12	12*	22	32	23	45	26	41	46	95	98	145		
								5	5*	20	36	35	51	31	37	19	28	64	159		
								65	390	76	565	198[1]	728[1]	120	1059	369	3123	152	1410		
								25	25*	8	10	101	178	209	324	48	96	139	213		
								17	25	3	5	306	448	144	246	63	93	110	134		
								10	10*	6	8	266	342	331	494	188	289	110	171		
								12	20	1	1*	472	591	522	599	604	789	453	580		
								52	85	459	827	1781	4562	1559	4965	1534	4803	784	1847		
								187	379	54	118	1029	3159	1284	3442	618	1279	385	1076		
51	51*	38	38*					438	822	209	374	12	21	13	23	77	118	159	192		
73	128	59	85			116	116*	103	133	111	285	331	921	299	862	791	1826	681	1216		
143	292	171	325			173	191	154	245	298	478	167	386	190	342	557	963	294	542	59	59*
159	222	98	249			45	45*	165	232	164	287	42	76	45	55	123	188	22	31	39	41
187	223	190	230			289	359	334	334*	591	806	105	197	200	285	178	222	24	51	82	136
377	604	385	560			183	183*	251	297	411	738	232	279	214	252	99	154	48	73	61	106
180[1]	604	174[1]	560			181	359	144	822	185	827	403	4562	430	4965	426	4803	264	1847		
450	795	250	408			192	192*	206	215	276	302	225	253	230	290	106	132	326	462	268	375
196	243	159	222			227	227*	240	287	345	411	323	357	274	312	150	192	120	154	92	106
387	670	200	253			160	160*	119	197	198	300	436	555	322	447	123	182	48	70	36	52
982	1787	412	578			1592	1592*	252	390	850	1103	258	444	321	428	161	345	90	197	60	118
307	710	506	607			129	200	233	386	69	100	1116	1522	840	1114	1067	1986	270	270	325	325
46	130	57	85			686	1263	132	154	402	1172	104	196	82	108	201	312				
38	91	44	94			213	298	332	364	179	418	46	70	22	35	297	376	220	306	363	563
15	23	50	67			218	266	454	811	544	943	401	965	349	906	550	791	371	578	363	578
58	88	118	222			146	146*	142	142*	106	172	390	614	415	724	543	1088	306	475	370	509
192	286	224	299					393	447	364	473	269	495	274	566	255	340	263	348	232	327
110	146	92	132			257	257*	243	243*	137	376	59	171	44	73	39	61	62	78	84	92
44	48	32	36			23	23*	28	34	21	26	82	144	67	91	32	45	686	1642	368	534
233	1787	175	607			339	1592	242	811	295	1172	320	1522	277	1114	304	1986	259	1642	228	578
56	63	58	67				32*	39	43	31	45	127	215	79	110	39	56	83	113	52	67
36	54	26	33				14*	30	40	57	130	225	330	118	150	38	56	33	56	22	39
18	38	40	73				12*	72	104	26	49	5534	10449	4739	9979	1139	1709	52	101	42	107
329	6086	105	261				42*			66	162	6487	9759	6012	8860	1395	4013	66	118	139	200
334	2671	138	181			159	170	102	129	167	338	614	1023	554	1168	558	826	219	425	239	343
57	75	74	118			88	119	149	179	382	465	120	191	130	263	478	782	534	928	616	1239
13	38	53	71			90	93	74	102	153	225	42	66	34	63	348	604	422	616	313	654
20	39	42	62			60	82	98	122	101	202	227	628	207	559	314	430	476	536	338	761
22	28	53	68			76	94	135	162	170	196	52	76	66	100	414	659	281	363	233	324
62	81	92	129			141	209	392	481	546	1190	116	201	125	187	115	143	118	142	87	104
59	76	53	66			43	48	61	73	65	95	153	256	140	23	87	112	126	168	210	476
35	56	20	58			15	15			33	48	99	108	86	95	63	107	197	344	255	361
377	6086	63	261			76	209	115	481	148	1190	1190	10449	1066	9979	420	4013	202	928	210	1239
50	81	61	96			27	39			34	44	111	131	88	123	27	57	4[illegible]	1014	374	1057
76	136	98	115			110	115			139	175	66	112	45	74	169	477	284	720	343	884
101	124	100	130			94	103	75	78	141	206	512	837	392	754	4574	10554	14645	32467	14127	31041
148	207	140	223			150	270	56	99	108	196	579	865	594	772	12079	25617	16889	40918	16363	39907
253	417	167	354			303	470	157	157*	271	551	211	358	199	275	591	666	582	736	594	696
53	85	158	254			332	387	17	17	758	1525	58	93	56	112	420	423	680	744	439	687
115	417	120	354			168	470			208	1525	269	865	244	772	3102	25617	6785	40918	6208	39907

present at Yankton, but continued growth and proliferation of forms discharged from the reservoir were the major factors involved. Greater plankton growth below than in reservoirs has been noted in other parts of the Missouri Basin (1 and 10). In some instances nutrients arising from oxidation of anaerobic hypolimnion discharges were involved, while in others no measurable environmental factors were detected. If rivers below reservoirs are very shallow (2 - 4 feet), benthic algal growths may usurp priority and reservoir plankton may decline. This state of affairs was noted below Alcova Dam in the North Platte River in 1950 (10), in the Big Horn River below Boysen Dam in May 1953, and below Ft. Randall Dam when releases were cut down in November 1953. Although the maximum plankton concentration did not occur within the reservoir, it may be safely assumed that clarification and other phenomena associated with its formation were responsible for maximums observed farther downstream.

Previous investigators (1 and 2) were of the opinion that curtailment of phytoplankton growth in the Missouri River was largely caused by excessive turbidity and high current velocity. There seems little reason to doubt that turbidity was an important factor, but current velocity in the Missouri is apparently not as much a limiting factor. Discharge below Ft. Randall Dam and at Yankton was practically the same during the August-November period in 1952 and 1953, but the river developed greater plankton density than the reservoir when clear water was provided.

With river regimen considerably more subject to reservoir control, the 1954 annual pattern of plankton density variation differed from that noted during any previous year (Figure 4). The severe decline of plankters that occurred in the early months of 1953 was not evident in 1954. Rather, there was a progressive increase in concentration, with only minor setbacks, from

early January until June. This growth, primarily composed of Asterionella and Diatoma elongatum, was augmented by a sudden increase of Synedra in May, and appeared destined to influence water quality at Yankton (despite carbon and chlorine treatment). However, it suddenly subsided during a period of extremely heavy local rains. Low level concentrations endured through most of July, but an increase to critical levels occurred again in August and September. Late summer and early fall growth failed to attain the maximum concentration observed in 1953. However, as in 1953, the density exhibited a downstream increase from Ft. Randall to Yankton. Plankton decline began again in late September 1954, but late December levels were considerably above those of 1953. An elevation in concentration occurred at Ft. Randall in early November.

Personnel limitations forced discontinuance of plankton analyses at Omaha during the critical period of growth in 1953. Analyses were resumed in October, 1953, and continued at weekly intervals thereafter. Records for 1954 show plankton features at Omaha to closely parallel events at Yankton and Ft. Randall (Table 23). Average density at Omaha was 30 per cent less and maximum concentration only slightly more than half of that attained at Yankton.

Average plankton concentration of Ft. Randall Reservoir discharge was the same in 1953 and 1954. The average figure is not indicative of the amount of variation or generally prevailing levels. Greater uniformity and higher levels over most of the year marked 1954. There were two annual maxima, but neither developed as dense a concentration as was exhibited by the single bloom in 1953. Plankton levels were also more uniform at Yankton in 1954, but there the average density fell far below the 1953 figure.

Yankton levels showed less variation and densities in higher ranges persisted for longer periods than was the case in 1953.

Pierre and Chamberlain plankton densities benefited in 1954 from the lower turbidities provided by Garrison Reservoir impoundment. Average concentrations at those two stations were approximately twice as great as in 1953. However, the maximum at Chamberlain was less than that developed in 1953. At Pierre, the 1954 maximum was more than three times as great as that of 1953. 1954 averages were about the same at the two localities (Table 23). Ft. Randall Reservoir rose to the overbank stage at Chamberlain in early November, and this event was probably of some significance in higher densities noted there in November and December.

Garrison Reservoir failed to respond to the conditions of uniform discharge that elicited the late summer and early fall plankton bloom in Ft. Randall and below in 1953 and 1954. Maintaining this individualistic pattern, it developed its densest observed growth of the year in December when Ft. Randall was near its annual minimum. Through December 31, plankton growths below Garrison did not attain a level troublesome to water treatment. In general the level at Mandan was very close to that of Garrison discharges. The average was somewhat greater but the maximum fell below that of the reservoir (Table 23). The November and December growth at Garrison apparently was responsible for increases all the way down to Chamberlain (then a part of Ft. Randall Reservoir) as the same dominant form (Asterionella) was involved (Figure 4 and Table 21). The December decline at stations below Mandan appeared to be associated with the onset of ice cover.

In 1955, no significant concentrations appeared above Garrison Reservoir; and within that body of water, growths to near critical levels were noted only during the first five months. The densities recorded in January represented the continuation of the Asterionella proliferation which began in October, 1954.

The river below Garrison Dam showed close agreement with the reservoir down to the vicinity of Mandan. Mobridge density declined in May and increased again in July. Thereafter, numbers at that point exceeded those recorded at Garrison until December. At Pierre, higher densities were also evident over a greater part of the year, maximum numbers being observed in August. Chamberlain attained high concentrations in April, June, and August, but exhibited a decline in May. Ft. Randall influences upon numbers of river plankton extended down to Yankton; and maximum densities occurred in May, a time of decline in inflowing water at Chamberlain. Another increase occurred in August; levels showed little change in September. Influences of Niobrara River contributions were evident at Yankton in July and August, when water entering from that tributary augmented plankton concentration by introduction of such forms as the Rhizosolenia group and Ankistrodesmus. Concentration in the Niobrara far exceeded any found in the Missouri or its reservoirs.

Densities at Omaha and Council Bluffs generally ranged far below to slightly below those at more upstream stations, yet exhibited an increase in December that was completely out of line with events upriver, although involving practically the same organisms that were then dominant in Ft. Randall releases. Omaha and Council Bluffs infrequently exhibited concentrations in the same range.

Maximum densities recorded in and below Garrison Reservoir, at Mobridge, Chamberlain, Ft. Randall, Yankton, and Omaha, were high enough to be considered critical from a water quality standpoint. On a monthly basis such levels occurred at Yankton in May, at Chamberlain in April, and at Omaha in December.

Entries in Table 23 show that maximum production in 1955 occurred within Ft. Randall Reservoir. The annual average at Yankton closely approached that of Ft. Randall, but the lower station benefited from growths introduced by

the Niobrara River. With this exception, there was a general decline in plankton density (Mobridge and Pierre are excluded from this account) below reservoirs. A similar decline was evident below Garrison during the last six months of 1954, but Yankton showed no significant decline below Ft. Randall releases. Omaha's average was below that of Yankton each year of record.

During its early days of impoundment, plankton forms that developed in Ft. Randall Reservoir increased their concentration when discharged to the river below. Higher annual densities at Yankton during that period were not occasioned by Niobrara inflow, but by continued proliferation of plankters originating in the reservoir. In 1954, there was no significant annual difference in density between Yankton and the reservoir releases; and in 1955, a slight increase, referable to Niobrara River augmentation, was evident at Yankton. However, the highest 1955 density at Yankton in May resulted from continued growth of Ft. Randall forms. Plankters exhibited aftergrowth in 1955 upon release from Garrison Reservoir, beginning in the vicinity of Mobridge, following declines at Mandan. Decreases at Mandan may have resulted from sampling at a point unrepresentative of the major discharge.

Plankton growth in the reservoirs exhibited characteristic lentic fluctuations with months of very low densities following periods of maximum or near maximum concentrations. River stations did not usually exhibit either the high or the low extremes found in reservoirs.

In 1956, Garrison Reservoir developed noteworthy plankton densities in April, May, and October (Table 23). The river above Garrison experienced its highest concentration in October, but had relatively abundant growths also in April, July, August, and September. Only in April and October were its increases accompanied by upsurges in Garrison Reservoir. Survival of reservoir plankton below Garrison Dam was poor and very low densities prevailed from Mandan to

Pierre. Chamberlain experienced more significant concentrations in summer and early fall that sometimes had the same dominant organism that prevailed in Garrison Reservoir.

In line with qualitative similarities already mentioned, Fort Randall Reservoir also resembled Garrison in developing its highest densities in the spring. However, accelerated growth was first evident in March and a more pronounced decline occurred in May. The highest monthly average density was about twice as great as the highest attained in Garrison.

Yankton experienced greatest concentrations in March and April and maintained monthly maximums in near critical ranges for water treatment over the period May-September. Monthly maxima at Omaha attained this level over the period May-August, a pattern paralleled by Council Bluffs samples that exhibited slightly greater concentration. Due to paucity of reservoir samples, Gavins Point influences at Yankton and below cannot be estimated. Concentrations there closely approached Yankton densities in May, June, and September.

Plankton growth was relatively dense in Garrison Reservoir during the first five months of 1957 (Table 23). The major number of plankters appeared to inhabit surface or near surface waters, since comparable concentrations appeared in reservoir releases only in April and May. The river above this reservoir approached it in plankton concentration only in April. Densities at Mandan closely paralleled those in reservoir discharges, except in June when they were three times as great. Mobridge had greatest numbers in April, May, and June.

Chamberlain experienced its most significant algal growth in June when Ft. Randall Reservoir (just above dam) reached its semi-annual minimum. Ft. Randall densities were greatest in March and April. Reservoir releases closely resembled surface waters only in April and June. Maximum growths occurring at

Yankton in March and April were evidently initiated in Gavins Point Reservoir where a density of 21,261 per ml. was found in April. Responsible organisms increased their numbers below Yankton and maxima for the river were found at Omaha and Council Bluffs. The plankton group responsible for exaggerated densities in and below Gavins Point was the dominant form in water released from Ft. Randall. Its accelerated growth in Gavins Point may have represented the "initial bloom" for that reservoir, but a vigorous aftergrowth occurred in the river.

Discussion of Plankton

Phytoplankton composition and concentration varied in manners that reflected operation of a wide range of phenomena. No noteworthy or authentic autochthonous main stem growth was noted in the Central Missouri River until some impoundment was realized in Ft. Randall Reservoir. As other reservoirs came into being a strong tendency toward individuality was apparent, but decided leanings toward uniformity were also evident at times. Some populations that developed in one reservoir eventually assumed dominance in a lower impoundment and the river between. Other dominant lake populations failed to survive river conditions, and still others developed in different reservoirs at the same time although absent in intervening stream reaches. Several reservoir populations increased their density in the river below the impoundment(s). Distance between reservoirs and their relative sizes were important factors in determining extent of influence any one had upon its downstream neighbor.

Seasons of greatest plankton density varied among various reservoirs and during different years. In 1953, greatest growth in Ft. Randall Reservoir and the river below came in late summer and early fall; a vigorous growth occurred in May and June the following year, and a lesser increase came in August. In 1955, maximum growth was again in May and other "bloom" months were

March, August, and September. In 1956, maximum density was observed in March, although April had the highest mean density. The spring elevation continued through May, and another proliferation was evident in August. In 1957, the spring "bloom" endured over March and April.

Garrison Reservoir records were started in July, 1954, and a moderate growth of Asterionella was noted in December of that year. The maximum growth for 1955 occurred in April, and high levels were also observed in March, May, and October. In 1956, levels representing accelerated growths were evident in April, May, and October. 1957's highest average occurred in February and the observed daily maximum in January. March and May experienced more moderate "bloom" conditions.

Gavins Point Reservoir had increased proliferation in May, June, and September, 1956, and in April, 1957 (one record). Yankton results indicate very pronounced growths in this reservoir in March and April.

Reservoirs showed no pronounced agreement, but spring growth increases were characteristic of all three of record.

Reservoirs

Available personnel resources largely limited sampling and analysis to situations that would be most informative of major and general water quality changes. Detailed knowledge of reservoirs was considered desirable and they were studied as time permitted. Data acquired is very fragmentary and is presented here largely as reference material. General thermal and chemical stratification of any duration was expected to be detectable by routine sampling above and below dams--and it was, as indicated previously.

Ft. Randall Reservoir

In 1952 and 1953, this reservoir did not acquire a great volume of storage (Figure 5) and intake apertures mixed water from all levels into discharges. Samples taken below the dam were therefore more representative of the reservoir as a whole than the surface samples from just above the dam. The Melosira granulata angustissima bloom that began in early August, 1953, was at first most concentrated at depths of 15 to 30 feet, but the zone of maximum proliferation moved to the surface on September 15, and remained there until this organism disappeared in late November. Temperature was uniform at all depths, and this diatom may have been reacting to diminishing light intensity. Chemically, surface waters differed from discharges in oxygen concentration, usually as related to air draft to flood control discharges, and in organic nitrogen content. The latter was usually greater in surface layers.

Storage volume was considerably augmented in late 1954 (Figure 5). Chemical stratification occurred in the area just above the dam for a brief period in late July. This condition lowered pH and oxygen, and elevated alkalinity, hardness, and total phosphorus in discharges. It also led to development of nitrite nitrogen in deeper layers. Organic, ammonia, and nitrate nitrogen were generally more concentrated in surface waters in 1954, and phosphorus reached a peak value near the surface in June.

A vertical series of samples collected one mile above the dam on September 21, 1954, gave the values shown in Table 24. Maximum depth was 95' at this point. Thermal stratification was lacking, and the only chemical difference was a slight increase in alkalinity and hydrogen ion concentration near the bottom.

Three vertical series were taken in Ft. Randall Reservoir on July 26 and 27, 1955 (Table 25). Ft. Randall deviated from Garrison Reservoir in some

Table 24.
Thermal and Chemical Features of a Vertical Series of Samples, Fort Randall Reservoir, September 21, 1954

Depth in feet	3	15	75	90
Temp. °C.	20	20	20	20
pH	8.3	8.3	8.3	8.2
CO_3 alk. ppm	2	2	4	4
HCO_3 alk. ppm	129	127	127	133
Oxygen % Sat.	87	87	87	87
PO_4 ppm	0	0	0	0
NH_3 N ppm	0	0	0	0
NO_2 N ppm	0	0	0	0

Table 25.
Vertical Variation in Temperature and Chemistry
Ft. Randall Reservoir, July 26 and 27, 1955

Table 25a.
Eleven Miles Below Chamberlain, Total Depth 27 Feet,
Suspended Silt Below 18 Feet, July 26, 1955

Depth Feet	1.5	9	18
Temp. °C.	26.0	25.5	25.5
pH	8.4		8.4
CO_3 Alk. ppm	18.0		18.0
HCO_3 Alk. ppm	127.0		128.0
Oxygen ppm	8.0		8.0
NH_3 N ppm	0.1		0.1
NO_2 N ppm	0.0		0.0
PO_4 ppm	0.0		0.0

Table 25b.
Forty-Five Miles Above Dam, Total Depth 63 Feet,
Suspended Silt Below 61 Feet, July 27, 1955

Depth Feet	1.5	13.5	27	40.5	60
Temp. °C.	26.75	26.5	26.0	26.0	26.0
pH	8.3	8.2	8.2	8.2	8.2
CO_3 Alk. ppm	14.0	12.0	10.0	10.0	8.0
HCO_3 Alk. ppm	137.0	139.0	142.0	141.0	144.0
Oxygen ppm	7.2	6.4	6.4	6.4	4.8
NH_3 N ppm	0.1	0.1	0.1	0.1	0.3
NO_2 N ppm	0.0	0.0	0.005	0.005	0.01
PO_4 ppm	0.0	0.0	0.0	0.0	0.0

Table 25c.
Two Miles Above Dam, Total Depth 98 Feet, July 27, 1955

Depth Feet	1.5	13.5	27	40.5	54	67	80.5	94
Temp. °C.	29.0	27.0	26.75	26.0	26.0	26.0	24.75	23.5
pH	8.3	8.3	8.3	8.2	8.2	8.2	3.1	7.8
CO_3 Alk. ppm	12.0	12.0	10.0	8.0		8.0	4.0	0.0
HCO_3 Alk. ppm	135.0	132.0	135.0	137.0		13[illegible].0	141.0	148.0
Oxygen ppm	8.0	7.2	7.2	7.2	6.4	6.4	5.6	2.4
NH_3 N ppm	0.1	0.1		0.1		0.1	0.1	0.1
NO_2 N ppm	0.005	0.005	0.01	0.01	0.01	0.005	0.0	0.005
PO_4 ppm	0.0	0.0		0.0		0.0	0.0	0.0

respects, and was not quite the same at different locations within itself. Shallow water near Chamberlain (Table 25a) was characteristic of upper reservoir reaches in the deep layer of soupy suspended silt and general uniformity of water above. At the midway point (Table 25b), suspended silt occupied only the lower two feet of water, and chemical variation was evident at different depths. Nitrite was absent in upper water and increased with depth, beginning at 27 feet--quite the reverse of Garrison Reservoir on July 19 (Table 27). Oxygen exhibited a sharp decline at 60 feet; pH did not change with depth, but some decrease and increase with depth were apparent in monocarbonate and bicarbonate alkalinity, respectively. Ammonia nitrogen increased abruptly at 60 feet.

Two miles above the dam (Table 25c), the reservoir had changed little. Temperature at 67 feet was the same as recorded at 60 feet, 43 miles above. Similarly, pH, alkalinity, and oxygen variations were essentially the same down to 67 feet. The oxygen decline near 60 feet at the middle reservoir station resulted from proximity to the bottom. The same sudden change was evident at 94 feet near the dam. Nitrite occurred at all depths except 80.5 feet at the

lower station. Greatest concentration was found between 27 and 54 feet, a decline to 0.0 occupied the distance from 54 to about 81 feet, but it reappeared at 94 feet. Ammonia nitrogen was most concentrated at the surface and at middle depths.

Vertical series samples, and differences at times evident between surface waters and discharges, indicate that some chemical variation occurs from surface to bottom in the absence of a definite thermal stratification with three or more density layers. The absence of thermal layers was definitely shown by declines of only 0.75° C. in 60 feet and 3.5° C. in 94 feet.

Variation in nitrite over vertical distances strongly suggests its major production by zooplankters, many of which carry on diurnal vertical migrations.

Longitudinal variation in Ft. Randall Reservoir was not marked with respect to any features analyzed in the vertical series. Hardness in surface water, however, increased from 208 ppm 11 miles below Chamberlain to 228 ppm two miles above the dam.

Garrison Reservoir

Volume buildup over the period 1954-1957 is shown in Figure 5. Vertical series taken in 1954 (Table 26) and 1955 (Table 27) showed no established thermal stratification, but water chemistry changed somewhat from surface to bottom in 1955. Chemical features measured indicate that homogenous water extended down less than 27 feet during a calm, bright day. Oxygen and carbonate decrease and bicarbonate increase are referable to increased effects of decomposition isolated from aeration and photosynthesis. It is assumed that nitrite nitrogen was produced by zooplankters. No biological samples were taken.

Taste and Odor Developments in Public Water Supplies

Prior to 1953, taste and odor difficulties at Missouri River water plants (Williston to Omaha) were confined to brief periods in spring and early summer.

Table 26.
Thermal and Chemical Features of Surface and Bottom Waters,
Garrison Reservoir, September 15, 1954
Maximum depth 41 feet

Depth in Feet	3	38
Temp. °C.	15	14
pH	8.5	8.5
Oxygen % Sat.	85	82
PO_4 ppm	0	0
NH_3 -N ppm	0.25	0.2
NO_2 -N ppm	0	0

Table 27.
Vertical Variation in Temperature and Chemistry, Garrison
Reservoir, July 19, 1955, 1 Mile Above Dam, Total Depth 85 Ft.

Depth in Feet	1.5	13	27	40	54	67	81
Temp. °C.	21.5	21.0	20.5	20.0	19.5	18.5	18.0
pH	8.2	8.2	8.2	8.1	8.0	8.0	7.9
CO_3 Alk. ppm	8.0	8.0	10.0	4.0	0.0	0.0	0.0
HCO_3 Alk. ppm	134.0	135.0	133.0	140.0	146.0	147.0	148.0
Oxygen ppm	8.0	8.0	7.2	7.2	6.8	5.6	4.8
NH_3 N ppm	0.0	0.1	0.1	0.1	0.1	0.1	0.0
NO_2 N ppm	0.02	0.02	0.02	0.02	0.01	0.0	0.0
PO_4 ppm	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Operators generally were of the opinion that such problems were caused by organic materials brought into the river by surface runoff, pothole drainage, etc. No operator could recall trouble at seasons other than the high runoff period in spring and early summer, and all observed that such problems were of short duration.

On August 21, 1953, the Yankton, South Dakota, water superintendent was notified through appropriate channels of impending plankton increase to nuisance levels. Activated carbon treatment was immediately instituted at the water plant, but the night operator neglected to maintain dosage on August 26, and a very unsavory taste appeared in treated water on August 27. Many complaints were received from consumers, and matters were eventually brought under control with increased carbon and chlorine dosage. This treatment was continued until mid-October, but unpalatable water again occurred for a short period beginning September 15. Complaints poured in again October 24 after carbon dosage had been discontinued for one week, and carbon application was reinstituted and continued for the rest of the year.

This taste and odor problem continued for several weeks after plankton densities had declined to low levels, and it would seem that the later tastes and odors were attributable to compounds and/or organisms associated with plankton decay. The problem did not occur at Omaha or Council Bluffs.

In 1954, Yankton water operators again had advance notice of increasing algal densities and were able to institute appropriate remedial measures before unsavory water occurred in the spring. Heavy rains that brought an abrupt end to the spring plankton bloom were of inestimable assistance. Mandan water supplies developed a slightly unpleasant taste in December.

In March, 1955, Garrison discharges had a fishy odor, and severe tastes and odors developed at Yankton from materials cleaned out of the settling basin. The fishy odor was still evident below Garrison Dam in April; and foam floating there had a greenish-yellow color that was not associated with algal cells but with a pigment in solution. Mandan water plant operators received several complaints about tastes and odors in their finished water. April was a month

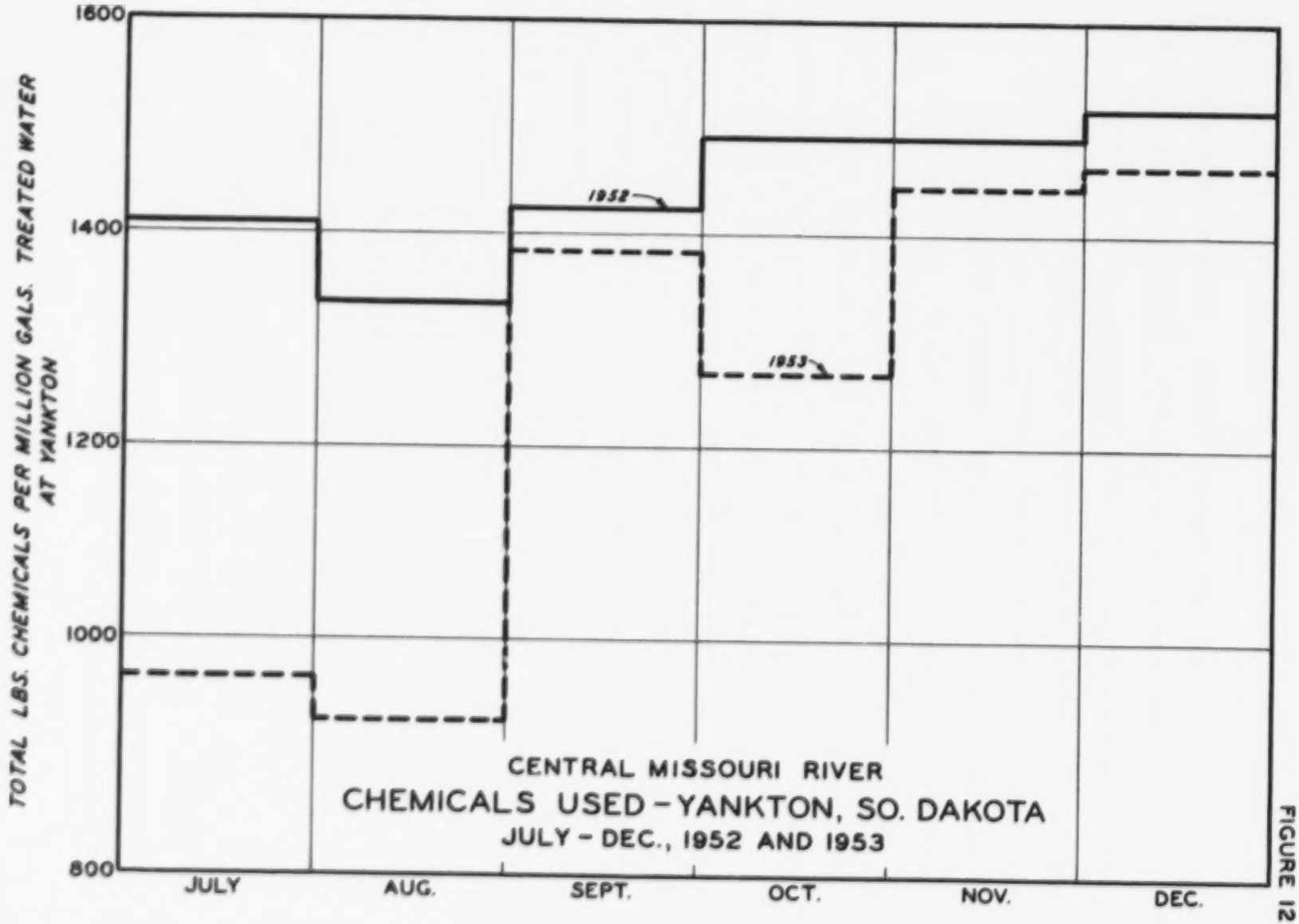
of high plankton concentration in Garrison releases. Mandan had a less dense population, but was not immune to the effects of plankton detritus. Operators alleviated the condition with increased dosages of appropriate chemicals.

On April 18, 1955, the Chamberlain water department was notified through the South Dakota State Department of Health of a probable algal increase to a nuisance level. Water operators immediately increased carbon and chlorine dosages and suffered no complaints from tastes and odors in finished water. Yankton water operators were similarly notified on May 9, and they promptly instituted remedial measures. Their attempts were not completely successful, as some odor was present in finished water until May 31. However, they received few complaints from city residents.

Mild tastes and odors were evident in finished water at Mandan on May 21, shortly after carbon application was reduced. Several complaints arose from poor palatability of Bismarck water in early May, but objectionable substances disappeared about May 20.

In June, the Public Health Service notified the Mobridge water plant, through the usual channels, of increasing algal density; but no problem occurred. A minor taste and odor problem developed at Chamberlain in early July, but proved amenable to control through increased use of carbon. Mandan experienced some impairment of water quality on July 5 and 6. In August the Public Health Service again furnished notice of impending plankton increases to water operators at Chamberlain and Yankton; and they were able to maintain a palatable water through increased application of carbon and chlorine. Chamberlain experienced some trouble with oil slicks that were windblown upstream from the sewer outfall.

In 1956 and 1957, advance notice of impending algal increases and prompt



CENTRAL MISSOURI RIVER
CHEMICALS USED - YANKTON, SO. DAKOTA
JULY - DEC., 1952 AND 1953

FIGURE 12

institution of carbon treatment generally kept tastes and odors below the nuisance level. Breakdown of the carbon feeder at Mandan in early April, 1956 (just after breakup), allowed a very disagreeable taste in finished water. Bismarck noted the undesirable condition of raw water at that time, but was able to keep matters under control with carbon dosage. In early June, 1956, both Bismarck and Mandan experienced a medicinal taste in finished water. In March, 1957, Yankton experienced a vegetative taste that endured for several days. No other incidents were reported.

In recent years the ray fungi (Actinomycetes) have received considerable attention as causative agents of unsavory tastes and odors in water supplies the claim being made in some quarters (11) that all naturally occurring problems of this sort are associated with these fungi, either by their growth in turbid water or as parasites in algal cells. Opportunity to evaluate the role of Actinomycetes in water supplies taken from the Missouri River has not existed; yet, very few tastes and odors have occurred unassociated with algal blooms, most exceptional cases occurred during declines of dense growths. Algae have been involved, either directly or indirectly, in establishment of conditions leading to taste and odor production.

Other Reservoir Relationships to Water Treatment

Attempts to relate water treatment changes to outside events are generally unsuccessful, as many factors, process and personnel changes, alterations, improvements, enlargements, intake relocations, etc., obviate comparisons of any two extended time periods. Records obtained from all Missouri River water plants from Mandan, North Dakota, to St. Charles, Missouri, indicate, with one exception, that reasonably valid comparison of pre- and post-impoundment

practices is not possible at this time. At the exceptional water plant, Yankton, South Dakota, operation and personnel remained the same over the period 1952 to 1954, and changes in chemical usage in 1953 and 1954 are believed due to reservoir influences. Pounds of chemicals required to treat one million gallons of water over the last six months of 1952 and 1953 are shown in Figure 12. Treatment costs on this basis were considerably lower in 1953. Lower and more uniform turbidity and hardness were given as factors permitting savings in chemicals, largely softeners and coagulants. Increased carbon and chlorine dosage were needed to control tastes and odors, but added costs in this regard were exceeded by savings in softeners and coagulants. 1954 costs were generally below those of 1953 (Figure 13), especially in summer and fall when reservoir releases largely determined the river discharge pattern. Savings were again largely related to softening and coagulation. In softening, the greatest savings were realized in chemicals used to reduce carbonate hardness.

The Chamberlain, South Dakota water plant has experienced difficulties with changing water quality that appears to be related to varying wind direction over Ft. Randall headwaters. Investigation into these phenomena has not been possible, but such problems have ceased when declines in reservoir level have moved the headwater area downstream from this water plant.

Economic Portent

Observations over the five year period 1952 - 1957 suggest that water quality changes wrought by this reservoir system were of the sort that would be more frequently beneficial than harmful to water use. Water treatment was complicated and/or made more costly by tastes and odors developed from phytoplankton and by mineral increases at times in Garrison Reservoir. However, mineral and

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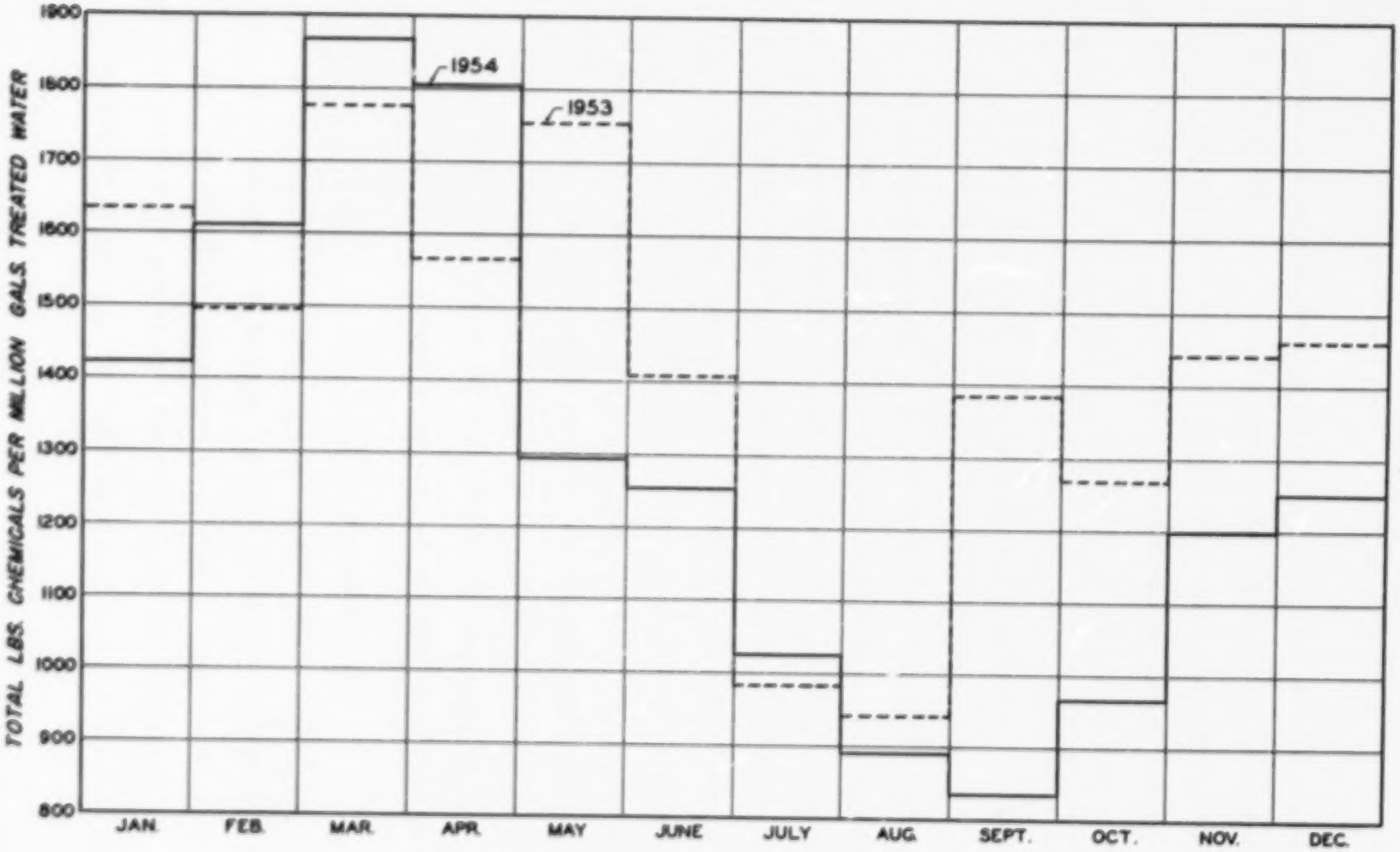

CENTRAL MISSOURI RIVER

CHEMICALS USED - YANKTON, SO. DAKOTA

JAN. - DEC., 1953 AND 1954

FIGURE 13

turbidity reductions such as arose in Ft. Randall Reservoir should be expected to reduce cost of water treatment; and such benefits were definitely shown over a three-year period of uniform operations at the Yankton water plant. Garrison Reservoir may be expected soon to reduce hardness and alkalinity each year, and it will probably then be recognized as an aid to better water quality. After water plants are "shaken down" and attain more uniform operation, savings accruing from lesser turbidity and mineral concentration may reasonably be expected to generally compensate for the recently added expense of taste and odor control. It is suspected that variation caused by plant expansions, personnel changes, new plants, new processes, etc., have prevented realization or recognition at most water plants of treatment savings inherent in lowered turbidity and mineral content. Certain complications like varying water quality in reservoir headwaters will probably diminish in importance as water operators gain experience and familiarity with such conditions.

SUMMARY

1. This investigation, directed by the U. S. Public Health Service, was a cooperative project with the Missouri River Division, Corps of Engineers, the State Health Departments of South Dakota, North Dakota, Nebraska, and Iowa, the Wyoming Department of Public Health, and waterworks personnel at Council Bluffs, Iowa; Omaha, Nebraska; Yankton, Chamberlain, and Mobridge, South Dakota; Bismarck, Mandan, and Williston, North Dakota.

2. Study began in August, 1952, shortly after closure of Ft. Randall Dam and continued through June, 1957. Garrison and Gavins Point Reservoirs entered into the investigation shortly after closures of their dams in December, 1953, and August, 1955, respectively. Sampling sites represented the Missouri River reach Williston, North Dakota, to Omaha, Nebraska. Convenience of access,

availability of prior records, and the routine presence of cooperative personnel led to sampling at water intakes wherever possible.

3. River discharge was subject to considerable control by Ft. Peck Reservoir operations at the start of this study, but the broad area drained by the river below this dam contributed sufficient runoff to allow recognition of basic natural flow characteristics. Additional regulation provided by storage in Garrison, Ft. Randall, and Gavins Point Reservoirs allowed virtual control of the river beginning in 1955.

4. The major reservoir influence upon water temperature was delay of spring warming and fall cooling in the river below each. The larger volumes of water they provided offered greater resistance to temperature change than the natural river. Loss of turbidity and decline in the ratio of surface area per volume may have also had a hand in slowing response to temperature variation.

5. Turbidity of the Missouri River was quite high, but suspended sediment load in terms of dry weight per volume was not especially heavy, as turbidity was largely occasioned by small, flattened, clay particles that effectively excluded light while contributing no great mass of sediment. Most turbidity stemmed from surface runoff and bank erosion. The river was generally clear under ice cover but quite muddy at other seasons. Each reservoir had clear discharges after some impoundment was attained, and reductions of turbidity and suspended sediment load carried all the way to the Mississippi.

6. Photosynthetic precipitation reduced alkalinity in Ft. Randall Reservoir during all years of record except 1956, when it was not affected, and in Garrison Reservoir in 1954 and 1956. Hardness of inflowing water

decreased each year in Ft. Randall Reservoir and in Garrison in 1954 and 1956. In 1955 and 1957, leaching of the reservoir floor exceeded photosynthetic deposition and augmented hardness and alkalinity in Garrison. Over the period January, 1953, to June, 1957, precipitation of carbonate left about 765 x 10^6 lbs. of alkalinity and 2 x 10^9 lbs. of hardness on the floor of Ft. Randall Reservoir.

7. Supersaturated oxygen concentrations were induced by photosynthesis throughout the reservoir system and by air draft to flood control tunnels in Ft. Randall and Garrison Dams. The latter action, although influencing only short river reaches, could be of considerable help in aerating oxygenless hypolimnion water in the event of chemical stratification. Photosynthetically induced supersaturation occurred after some clarification was effected and was at times widespread in reservoirs and river.

8. Nitrogen cycle and phosphorus analyses were conducted at most stations over the period of study. Some special analyses, calcium, magnesium, silica, fluoride, sodium, potassium, sulfate, copper, and zinc, were performed at six localities over the period August, 1952 - December, 1953.

9. Chemical variations usually progressed rather slowly; weekly and biweekly analyses generally indicated seasonal characteristics as effectively as daily records. Reversals of native annual mineral trends occasioned by detention in impoundments attested to the tendency of seasonal discharge segments to maintain their individuality. Some mixing with waters ahead and behind induced more gradual appearances of extremes, but the bulk of each seasonal flow volume appeared to pass down the reservoirs as prior inflows made way for it.

10. The phytoplankton population of the Central Missouri River consisted of survivors from tributary introductions until clear water existed in and below

Ft. Randall Reservoir in late 1952. Populations characteristics of the main stem developed after this event. Various aspects of plankton growth are related in detail. Plankters exerted considerable influence upon water chemistry. Reservoirs and individual river reaches exhibited marked variation, and, rarely, somewhat unexpected resemblances. Populations were determined at times by individual reservoir influences and at times by basin-wide environmental factors.

11. Phytoplankters and their residues developed tastes and odors in water supplies, but such problems were gradually brought under control as operators acquired experience. Advance notice of impending algal "blooms" proved valuable to early control operations at water plants.

12. Turbidity and hardness declines occasioned by reservoir phenomena allowed substantial savings in softening and coagulating chemicals at the one water plant where operations were similar in pre- and post-impoundment years. Changed operation at other plants was related to expansion, relocation, etc., not to water quality variation.

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